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Fisheries Research Bulletin No. 5

Reproduction, Early Life History, and Age-growth Relationships of the New Zealand Pilchard, *Sardinops neopilchardus* (Steindachner)

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By
Alan N. Baker

Fisheries Research Division
New Zealand Marine Department

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Frontispiece: Fishburn and Perano families, of Queen Charlotte Sound, catching pilchards for groper bait by lampara seining.

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Reproduction, Early Life History, and Age-growth Relationships of the New Zealand Pilchard, *Sardinops neopilchardus* (Steindachner)

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New Zealand Marine Department

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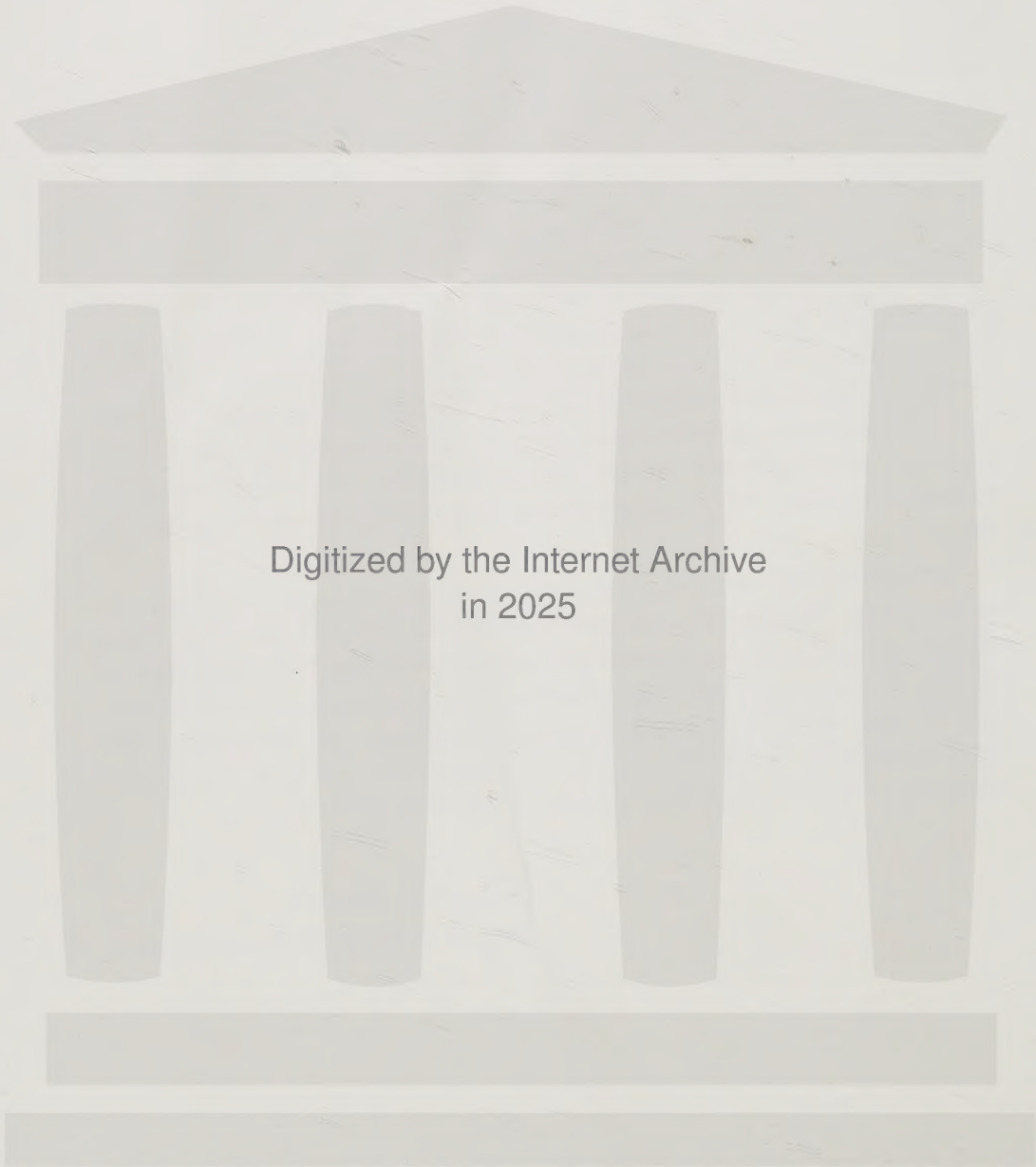
FOREWORD

ONE of the objects of research grants made to universities by the Marine Department is the encouragement of biological studies of fish of possible commercial significance. It is gratifying that Dr Baker's work, undertaken with such encouragement, should appear as a first contribution on a marine fish species in the new series of Fisheries Research Bulletins. It is also pleasing that Victoria University of Wellington should have agreed to publication in the series.

Clupeoid fishes are widespread and abundant and support some of the world's largest fisheries. Though the direct commercial potential of the New Zealand pilchard is as yet unknown, the species is undoubtedly important as a forage food for larger fish and could also serve as a source of protein in the form of meal. However, some knowledge of the biology and behaviour of the species is essential, and in this respect Dr Baker's work provides a foundation for further studies aimed at full and rational utilisation of the resource.

G. DUNCAN WAUGH,
Director, Fisheries Research Division.



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INTRODUCTION

This study on the life history of the New Zealand pilchard, *Sardinops neopilchardus* (Steindachner), was made during 1966-68 as part of a Victoria University Department of Zoology survey of the fishery resources of the Cook Strait, Marlborough Sounds, and Tasman Bay areas.

The objects of the study were:

(a) To determine the reproductive cycle of pilchards and to discover the time and place of spawning.

(b) To elucidate the early life history of the species, including the development of eggs and larvae.

(c) To investigate age-growth relationships of the pilchard.

The New Zealand pilchard belongs to the family Clupeidae (herrings, sprats, sardines, etc.), a commercially important group of pelagic fishes widely distributed in temperate and subtropical coastal seas. Species of the genus *Sardinops* (pilchards or sardines) are found in the temperate and subtropical Pacific and south-east Atlantic Oceans. Throughout their range pilchards have been the object of fisheries of varying intensities, most of which have been characterised by considerable seasonal and annual fluctuations in yield. Because of their commercial importance they have been the subject of much study, and consequently most of the *Sardinops* species are well known biologically (see Wheeler 1931, Rosa and Murphy 1960).

Sardinops neopilchardus also occurs in Australian waters, where some research has been carried out on its biology and an attempt has been made to base a fishery on it (Blackburn 1941 *et. seq.*, Humphrey 1960). In New Zealand, however, the biology of this species has been poorly understood, and it is not exploited much commercially.

The New Zealand pilchard has been recorded from Spirits Bay to Foveaux Strait (Fig. 1), and though records for the west coast are more fragmentary than for the east, the species is probably widespread in all coastal waters of both North and South Islands (see page 18). Various attempts have been made to utilise *Sardinops neopilchardus* commercially here, but none has been really successful.

In the 1880s the pilchard was regarded as a good commercial prospect and was the object of a small fishery in the Marlborough Sounds. Discussing the pilchard or "Picton herring" industry in the Sounds during that early period, Arthur (1883) quoted Mr A. G. Fell as saying, ". . . four smoke houses were kept going all last winter. The hauls made averaged one and a half to two tons, but at times ten tons have been landed". Sherrin (1886) also reported that pilchards were caught in large numbers in Queen Charlotte Sound and "converted by salting and smoking into the highly-esteemed Picton herring". During this period smoked pilchards were popular in North Island towns and were exported regularly to Fiji and other Pacific Islands (Phillipps 1929).

After 1900 the pilchard was caught less regularly in the Sounds and was used mainly as bait in the groper (*Polyprion oxygeneios* Bloch and Schneider) fishery. At Auckland pilchards caught in the Hauraki Gulf occasionally appeared on the market, but a fishery did not develop there. It was only in 1942 that a full-scale commercial operation began in the Marlborough Sounds. In 1938 the Marine Department suggested that by using purse seines for catching pilchards Cook Strait fishermen might well support a significant commercial cannery (New Zealand Marine Department 1938). After this report a small cannery was built at Picton, and in 1942 one vessel equipped with a purse seine began fishing for pilchards in the Marlborough Sounds and Admiralty Bay (Fig. 2). At first, catches were promising—274 tons in the first season—but later fewer fish were caught for the same effort, and in 1950 the company ceased operations. The yearly pilchard catches at Picton between 1942-43 and 1949 (New Zealand Marine Department 1948-51) were:

Year	Pilchards (tons)
1942-43	274.3
1943-44	266.9
1944	214.0
1945	72.9
1946	59.5
1947	4.8
1948	44.8
1949	11.1

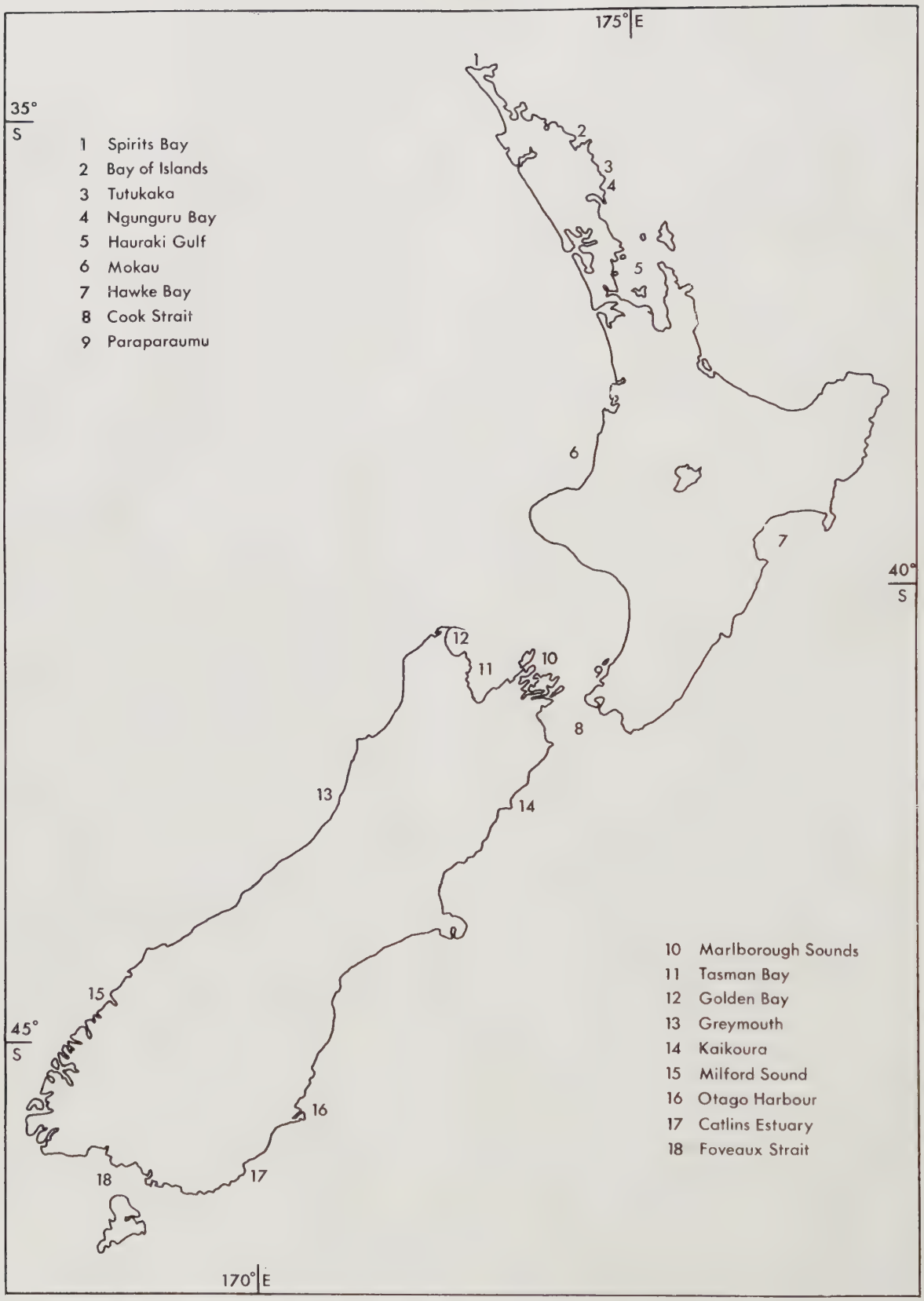


Fig. 1: Localities mentioned in the text.

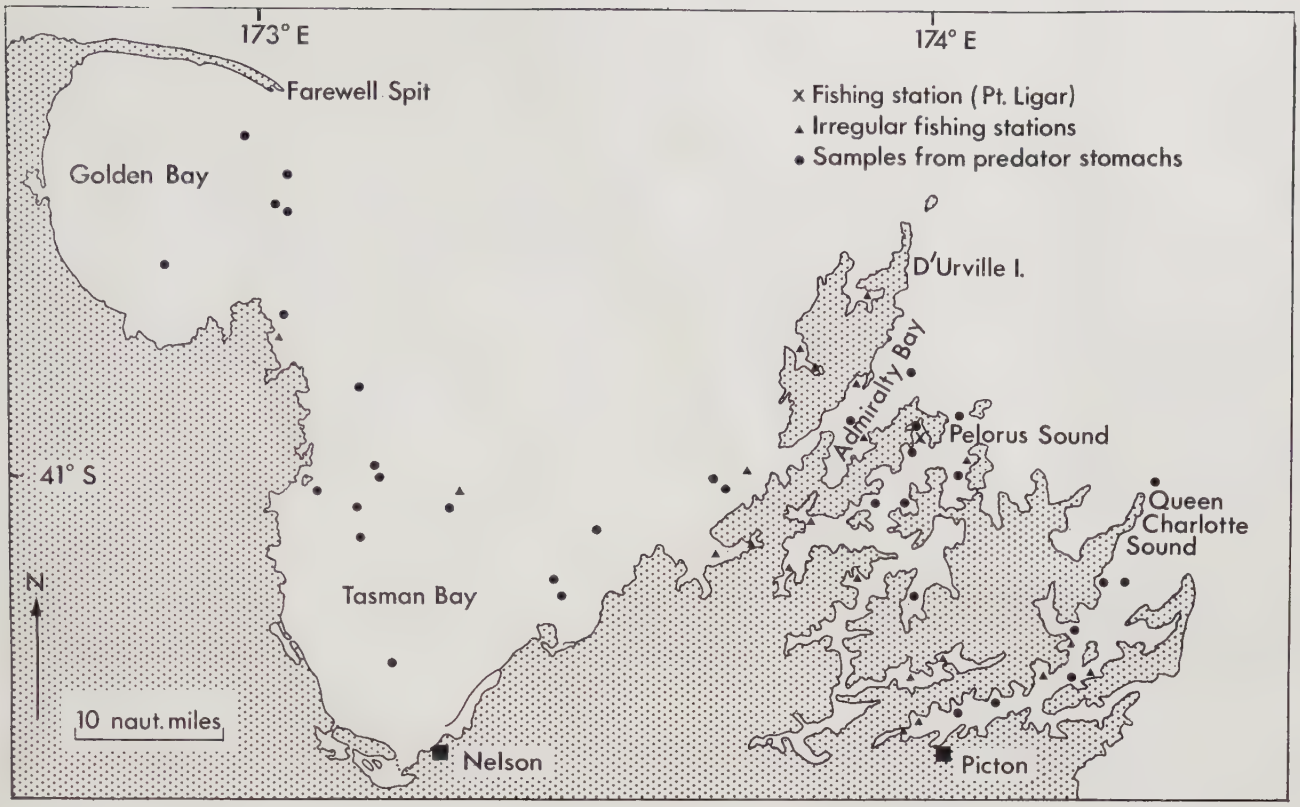


Fig. 2: The Marlborough Sounds-Tasman Bay area, showing the location of pilchard sampling stations.

The reasons for the decline in catches and final stoppage of pilchard fishing in the Sounds are obscure, but it seems that a scarcity of fish, market competition from imported products, and the accidental loss of the purse seine in 1950 all contributed to the closure of the company.

Since then pilchards have been caught sporadically for groper bait and have occasionally appeared on the Wellington fresh-fish markets.* General interest in the commercial potential of pilchards was revived in 1963, when the Nelson Cannery Exploration Company was set up to assess the suitability of yellow-eye mullet (*Aldrichetta forsteri* (Valenciennes)), pilchards, anchovies (*Engraulis australis* (White)), and kahawai (*Arripis trutta* (Bloch and Schneider)) for commercial utilisation. The project did not develop further, mainly because of insufficient data on the biology of these fishes and the lack of suitable fishing gear.

It was to provide some biological information that the present study on the pilchard was instigated, for in the late 1960s new interest was developing in the possibility of re-establishing a pilchard fishery in the Marlborough Sounds-Tasman Bay area.

The main limitations on the investigation described here were the relatively short time available for field work and some of the selective methods used to catch fish. Furthermore, a combination of a small research vessel and the notoriously variable weather in the Cook Strait region limited the study to the more sheltered waters of Marlborough Sounds and Tasman Bay. Pilchards are common in these areas, but numbers are probably small in relation to the total range and stock of the fish.

With its limitations, the present study on the biology of the pilchard can be regarded only as a basis for future extended work for comparison not only in the Marlborough Sounds-Tasman Bay area, but elsewhere in New Zealand.

* Since the manuscript was prepared for publication pilchards have been caught commercially for use as food at Marineland, Napier, and for live bait for tuna fishing.

MATERIALS AND METHODS

Figure 2 shows the localities in the Marlborough Sounds-Tasman Bay area where samples of pilchards were collected between January 1966 and February 1968. Most fish were taken from the Victoria University of Wellington's research vessel *Tirohia,* a modern 43-ft stern trawler equipped with a scanning echo-sounder and winches suitable for operating drift nets and plankton nets in sheltered waters.

Monthly cruises were made over the 2-year period, and because the research was mainly exploratory, the stations worked varied in number and locality with each trip according to prevailing biological and weather conditions. Whenever possible, six fixed plankton stations and one fishing station (Figs. 2 and 3) were worked each month. The plankton samples were collected to provide an index of the seasonal occurrence of pilchard eggs and hence the spawning season of pilchards. When samples included pilchard eggs, up to 10 extra stations were occupied to allow for a wider coverage of the spawning grounds.

Because eggs of other *Sardinops* species tend to be concentrated from near the surface to depths of 10 to 20 m (Dakin and Colefax 1934, Scofield 1934, Ahlstrom 1950, Davies 1956), sampling was concentrated on depths between 0 and 30 m. The following procedure was adopted at each plankton station:

(a) A 1-m-diameter net of 0.6-mm mesh size was towed horizontally in the upper 30 m of water for 15 minutes at 1 to 2 knots.

(b) The surface temperature was recorded, and weather observations were made.

(c) In February 1968, when an electrodeless induction salinometer with thermistor attachment became available, salinity and temperature profiles were measured at each station.

When pilchard eggs were found, a subsample was removed to jars of fresh, filtered sea water so that development could be followed, and the remainder of the sample was fixed in 5 percent

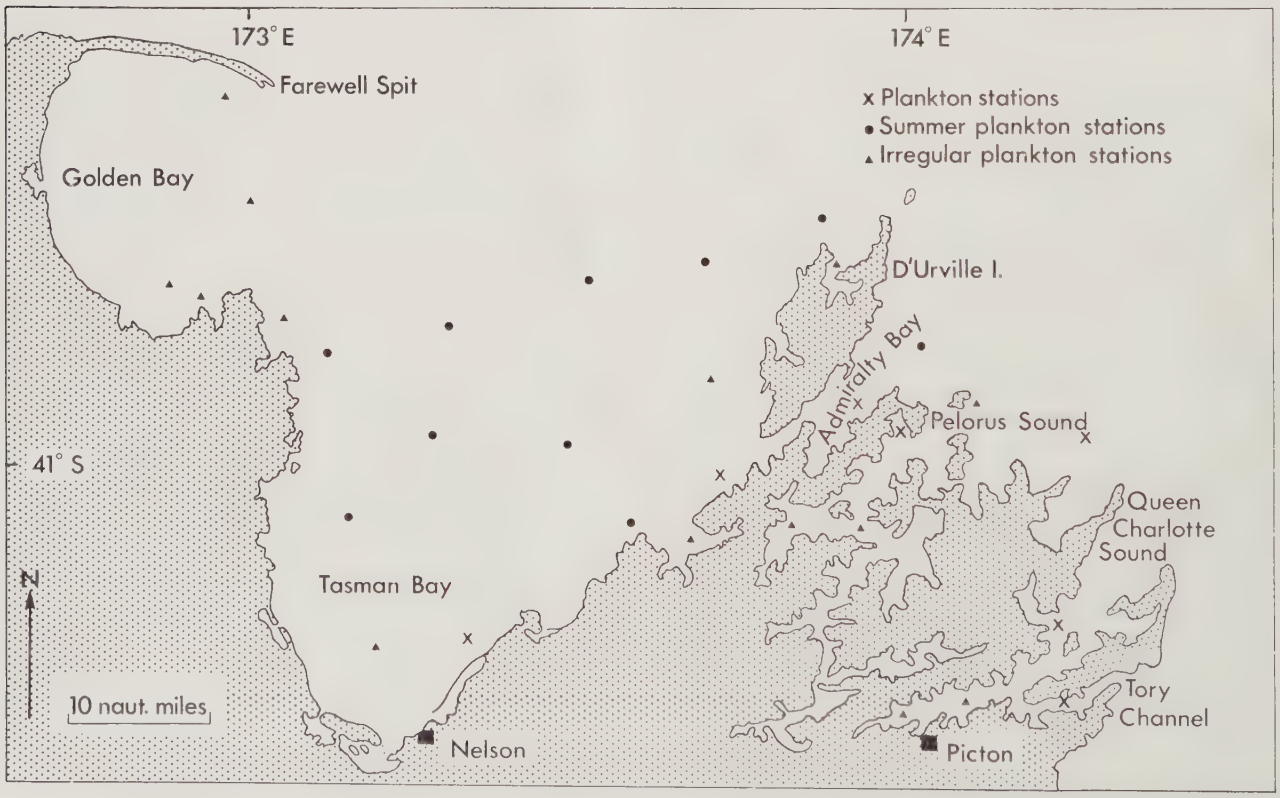


Fig. 3: The Marlborough Sounds-Tasman Bay area, showing the location of plankton sampling stations.

formalin. The movement of the vessel made it impossible to measure or photograph developing eggs accurately while at sea; hence they were fixed at timed intervals after capture and examined in detail ashore.

The following different methods were used to capture pilchards: lampara seining with a net lent and worked by Messrs A., J., and T. Fishburn, of Dryden Bay, drift netting, dip netting, hoop netting, and line and hook. The lampara net measured 200 fm long and 25 fm deep and had a $\frac{3}{4}$-in.-mesh bunt; the drift nets were 25 fm long and 4 fm deep, with stretched mesh sizes of $1\frac{1}{2}$, $1\frac{1}{4}$, 1, and $\frac{3}{4}$ in.

With the exception of one lampara shot at dusk, all fishing was done in the dark with submerged lights to attract fish. In the dark, with the engine off, surface schools could often be located by the phosphorescent activity around the fishes and by the characteristic flicking and fluttering sounds made by pilchards breaking the surface. When a school was sighted, the drift nets were run out and their level in the water was adjusted according to the distribution of fish as shown by the echo trace. A submerged light was left with the nets if they were some distance from the vessel, or lights were hung over the stern if the nets were attached to the ship. The duration of each set depended on the abundance of fish at the time. Short sets were generally desirable, because the longer the nets were down, the greater the chance there was of damage being caused by barracouta (*Thyrsites atun* (Euphrasen)) and dogfish (*Squalus acanthias* L.), which became entangled by their teeth or sharp dorsal fin spines.

Larval, juvenile, and occasional adult pilchards were caught with a light trap similar to that used in the South African pilchard investigation by Davies (1954). The trap was suspended from the main vessel or a tender and could be lowered to a depth of 30 m.

Many of the juvenile fish examined in this study were collected from the stomachs of predator fishes and birds: kahawai, barracouta, and yellowtail (*Seriola grandis* Castelnau) provided young stages, and gannets (*Sula bassana* L.) usually contained adult pilchards. Larval and juvenile pilchards were also found in the crops and stomachs of pied shags (*Phalacrocorax varius* (Gmelin)), red-billed gulls (*Larus novae-hollandiae scopulinus* Forster), and fluttering shearwaters (*Puffinus gavia* (Forster)).

To compare vertebral counts, pilchards were obtained from outside the study area. These fish, taken mainly between the Hauraki Gulf and Bay of Islands in northern New Zealand (Fig. 1), were collected from trawl nets, gill nets, beach seines, and from the stomachs of kahawai, yellowtail, yellowfin tuna (*Neothunnus macropterus* (Schlegel)), and striped marlin (*Tetrapturus audax* (Phillipi)).

A total of 10,090 pilchards (excluding early larvae) was examined from catches taken between January 1966 and February 1968, and a further 1,232 specimens collected in earlier years or from outside the study area were used in the study. Many of the latter specimens were from collections housed in the Dominion Museum, Wellington.

TREATMENT OF THE SAMPLES

All catches of pilchards were treated as follows:

(1) Each fish was measured lying on its right side from the tip of the lower jaw with the mouth closed to the tip of the hypural plate (body or standard length), the measurement being recorded to the nearest $\frac{1}{2}$-cm group. The groups used were 0-4 mm, 5-9 mm, 10-14 mm, etc.

(2) Fish were taken at random, and the first 100 from each sample were sexed and an index of sexual maturity was assigned to the gonads of each fish. During the spawning season up to 200 fish were examined in this way each month.

(3) Ovaries and testes of the 20 largest fish in the sample were removed and preserved in 5 percent formalin for later weighing and measurement of ova diameters.

(4) During measuring and sexing, up to 100 pilchards from each sample were selected for scale studies, fixed in 10 percent formalin, and, later, preserved in alcohol. Selection was based on the quantity of scales present on each fish. (Pilchard scales are deciduous and

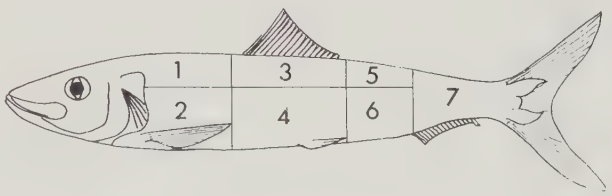


Fig. 4: Scale sampling sites on an adult pilchard.

are easily shed during capture. Therefore some samples were totally without scales and in others scales were missing from the sampling area.) Whenever possible, several fish of each $\frac{1}{2}$-cm length group were retained. In the shore laboratory these fish were remeasured to the nearest millimetre and weighed; their sex and stage of maturity were then recorded if these had not been determined previously. Where possible, 12 scales were removed from each fish for age determination, six being taken from each side of the body in the region behind the pectoral fin and below the dorsal fin (Fig. 4).

TAXONOMY AND DESCRIPTION

The genus *Sardinops* Hubbs, 1929, belongs to the family Clupeidae and contains five very closely related nominal species: the Australian and New Zealand pilchard, *Sardinops neopilchardus* (Steindachner), the South African pilchard, *Sardinops ocellata* (Pappe), the South American sardine, *Sardinops sagax* (Jenyns), the Californian sardine, *Sardinops caerulea* (Girard), and the Japanese sardine, *Sardinops melanosticta* (Temminck and Schlegel). Although relationships within the genus are still poorly understood, most recent workers (see Ahlstrom 1960, p. 417) regard *S. neopilchardus* as the most distinct member. The other four species are regarded as conspecific by some authors (for example, Ahlstrom 1960), whereas others have given them full specific or subspecific status. Svetovidov (1952) favoured the last ranking with *S. neopilchardus* as a subspecies of *S. sagax,* but Blackburn (1941 *et seq.*) gave it full specific status and stressed the very close relationship with other members of the genus.

SUMMARY OF THE PRIMARY SYNONYMY OF THE AUSTRALIAN AND NEW ZEALAND PILCHARD

Sardinops neopilchardus (Steindachner, 1879)

Clupea lata Richardson and Gray, 1843, p. 221 (*nomen nudum*).

Alausa melanosticta Valenciennes, 1847, p. 444 (not *melanosticta* Schlegel *in* Temminck and Schlegel, 1846, p. 237).

Clupea neopilchardus Steindachner, 1879, p. 12.

Sardinia neopilchardus McCulloch, 1919, p. 172.

Clupanodon neopilchardus: references in McCulloch, 1919, p. 173.

Amblygaster neopilchardus: references in McCulloch, 1919, p. 173.

Clupea melanosticta and *C. sagax:* references in McCulloch, 1919, pp. 172-173.

Sardinops neopilchardus Whitley, 1937, p. 116.

McCulloch (1919), Whitley (1937), and Blackburn (1941) gave bibliographies for the species up to those dates. The following references have been published since 1939 and have not appeared in a formal bibliography:

Sardinops neopilcharda: Phillipps 1940: 1-11; Graham 1953: 104-107.

Sardinops neopilchardus: Phillipps 1949: 13; Blackburn 1949: 9-86; 1950: 221-258; Blackburn and Tubb 1950: 9-74; Blackburn 1951a: 179-192; Blackburn and Rayner 1951: 1-8; Rapson 1953: 234-250; Blackburn and Downie 1955: 3-11; Blackburn 1960: 245-264.

The last detailed description of New Zealand specimens of *S. neopilchardus* was given by Arthur (1883); because the pilchard is often confused with the New Zealand sprat (*Sprattus antipodum* (Hector)) and the yellow-eye mullet (*Aldrichetta forsteri*), it is considered that a new diagnostic description is appropriate.

DESCRIPTION

This is based on 10 specimens 92 mm to 186 mm in body length, from the Marlborough Sounds, and one specimen 123 mm in body length, from the Bay of Islands.

Body elongate, oval in cross section. Ventral profile gently curved; dorsal profile less curved. Depth of body less than length of head. Two elongated scales at the base of the caudal fin; body scales very deciduous; scutes weakly keeled. Mouth terminal, with minute teeth only on posterior ventral surface of maxillary. Adipose eyelid present. Operculum with 4-6 radial striations. Gill rakers: 73-74 on the lower limb of the first arch, 45-48 on the upper limb. Fins: D = 17-19; A = 16-17, last 2 anal rays elongated. Caudal fin deeply forked. Vertebrae 49-52. Standard length to 213 mm.

Colour: Dark blue above, often with greyish transverse wavy bands which fade after death. A row of eight to 14 dark spots dorso-laterally along the body to just behind the dorsal fin; below this row the colour of the flanks changes abruptly to silvery bronze. The tips of the jaws are finely spotted with black; dorsal and caudal fins with fine black spots at margins.

TABLE 1: Details of vertebral counts from New Zealand pilchards

Locality	Number of vertebrae 49	50	51	52	Total No.	Mean	No. of samples	S.D.	S.E.	Range of means	Years collected
Port Ligar, Pelorus Sound	12	173	107	2	294	50.34	5	0.564	0.030	50.13-50.47	1966
Tasman Bay	2	20	8	0	30	50.20	1	0.375	0.068	50.20	1966
Total for Port Ligar and Tasman Bay	14	193	115	2	324	50.32	6	0.670	0.037	50.13-50.47	1966
Bay of Islands	6	10	12	1	29	50.28	1	0.825	0.015	50.28	1966
Tutukaka and Ngunguru Bay	2	23	13	0	38	50.29	1	0.558	0.090	50.29	1968
Hauraki Gulf	2	59	33	0	94	50.33	2	0.551	0.056	50.28-50.35	1964.1969
Total for Hauraki Gulf and north	10	92	58	1	161	50.31	4	0.583	0.045	50.28-50.35	1964,1969
Total for all localities	24	285	173	3	485	50.32	10	0.619	0.028	50.13-50.47	

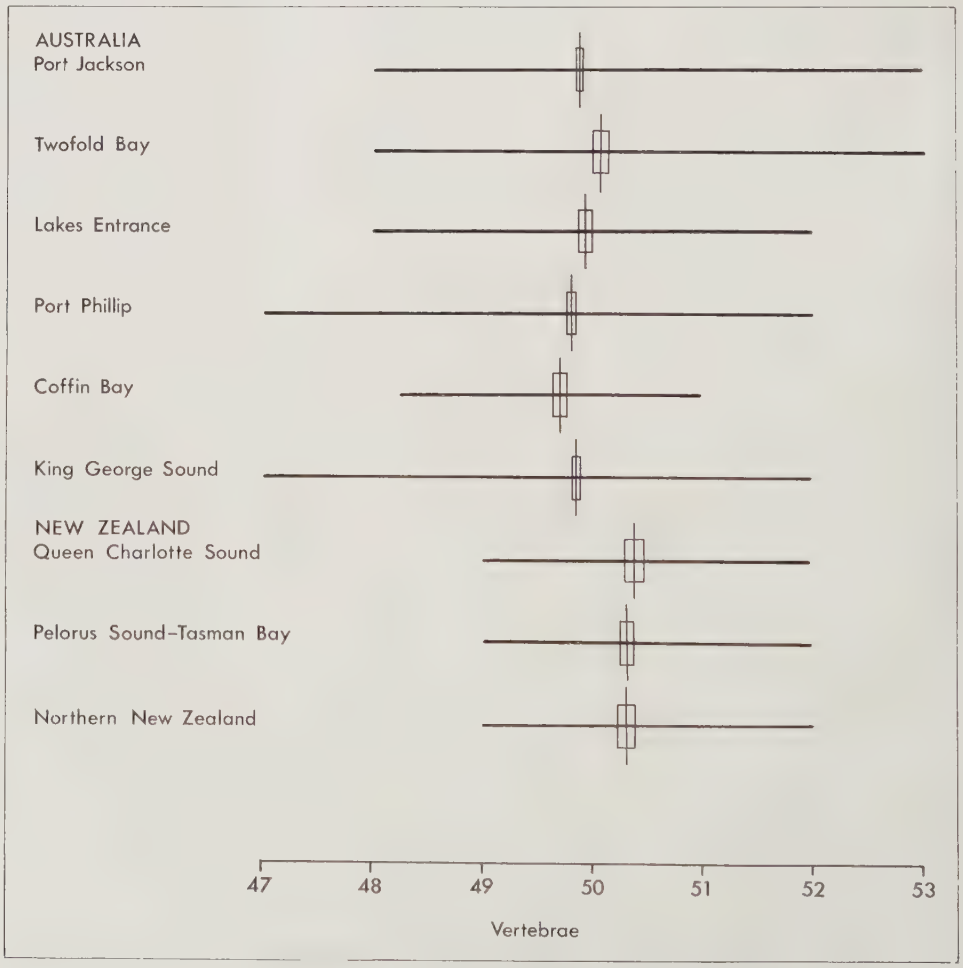


Fig. 5: Summary of data on vertebral counts of *Sardinops neopilchardus* from six Australian and three New Zealand localities (Australian and Queen Charlotte Sound data from Blackburn 1960). The horizontal line represents the range, the vertical line the mean, and the open rectangle twice the standard error each side of the mean. Comparison of the separation or overlap of rectangles yields *t* values (Hubbs and Perlmutter 1942).

RACIAL VARIATION

The New Zealand pilchard is externally identical to its Australian counterpart. It appears, however, that in New Zealand waters the species grows larger, has slightly larger eggs, and has a higher mean vertebral number than in Australian waters.

The maximum body length recorded for a New Zealand pilchard is 213 mm, whereas the largest Australian fish is 197 mm (Blackburn 1960). The newly fertilised egg of the New Zealand pilchard (at least in the Marlborough Sounds-Tasman Bay area) has a diameter range of 1.32 to 1.70 mm and a mean diameter of 1.53 mm; according to Dakin and Colefax (1934), similar measurements for New South Wales pilchard eggs are 1.27-1.50 mm and 1.44 mm.

The mean vertebral number for New Zealand pilchards examined during this study was 50.32 (Table 1). Blackburn (1951b) also counted the vertebrae of pilchards from Queen Charlotte Sound and found a mean of 50.39 for 249 fish. He concluded that as the New Zealand mean was significantly higher than any Australian means (49.0-50.08), New Zealand pilchards probably do not belong to the same population as Australian pilchards. Blackburn's most recent (1960) data on pilchard vertebrae are summarised with my New Zealand data in Fig. 5. It can be seen that the mean vertebral numbers for all the New Zealand material are significantly higher than those of the Australian samples.

A similar order of differences in means of vertebral counts has been used as evidence of heterogeneity and the distinctness of stocks within

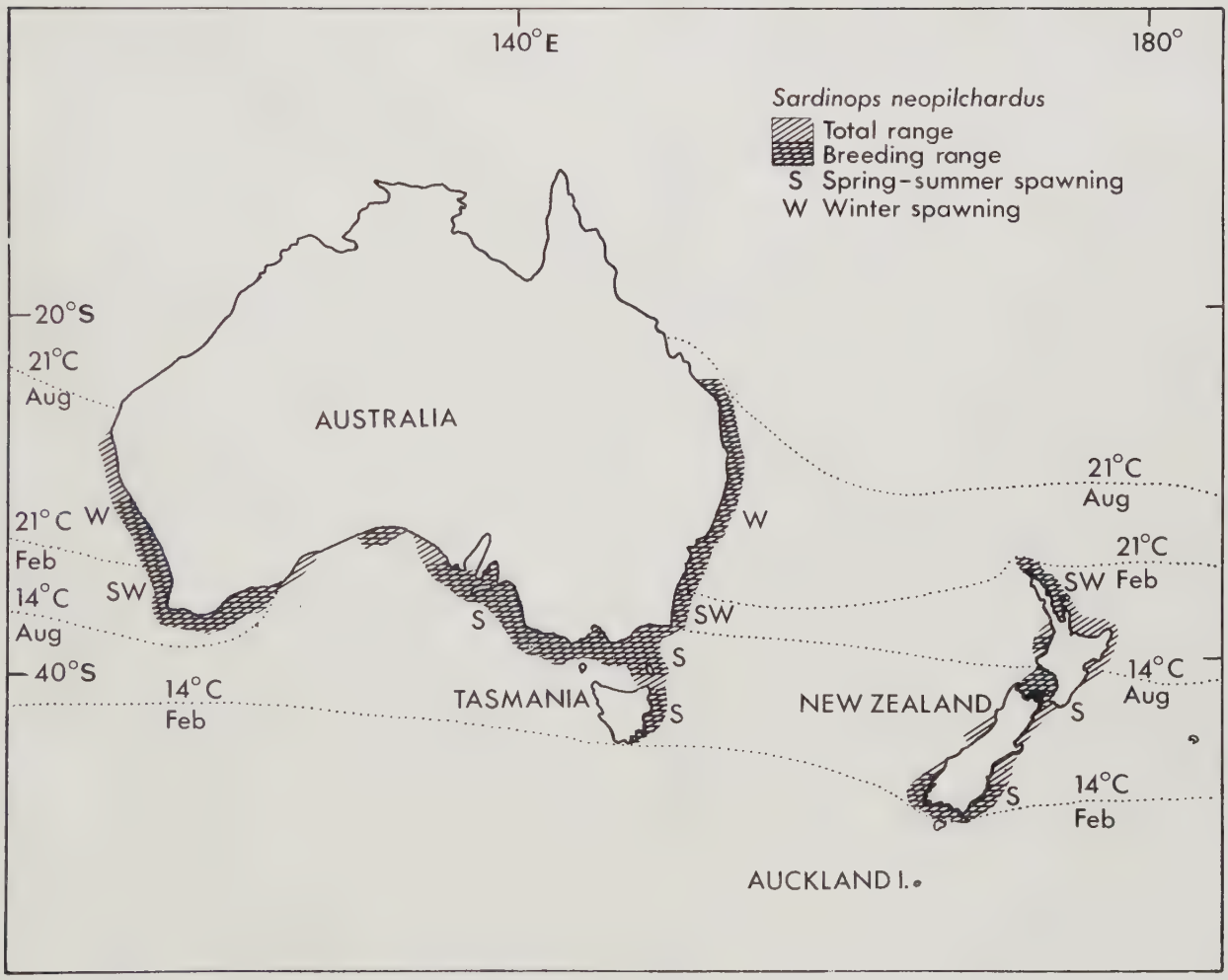


Fig. 6: Known total and breeding range of *Sardinops neopilchardus* in Australia and New Zealand in relation to the mean February and August positions of surface isotherms 14° and 21°C, and the distribution of known spring-summer and autumn-winter spawning areas (modified from Blackburn 1960).

the distribution of the Californian sardine by Clark (1947) and Ahlstrom (1960), and even smaller differences were used by Aikawa (1940) to identify races of the Japanese sardine. If it is presumed that there is a high degree of geographical isolation between the Australian and New Zealand pilchards, it is very likely that the differences in maximum size, egg diameter, and vertebral numbers are genotypic and that the New Zealand stock of *S. neopilchardus* is distinct from the Australian stocks.

DISTRIBUTION

In Australia *Sardinops neopilchardus* is seasonally abundant south of the Tropic of Capricorn (Blackburn 1950). In New Zealand it has been recorded from the southern and eastern coasts of the South Island, Milford Sound, and the Marlborough Sounds (Young and Thomson 1926 and references therein), as well as Auckland (Sherrin 1886), the Bay of Islands (Baker 1966), and Spirits Bay (Regan 1916). During this study specimens were also examined from off Mokau (north Taranaki), Napier Beach (Hawke Bay), and near Greymouth (South Island). This last collection is the first positive record of the species for the north-west coast of the South Island. Although there are few records of the species from the north-west coast of the North Island, and Regan's specimens were larvae, it seems likely that the pilchard is widespread in New Zealand coastal waters (Figs. 1 and 6).

Pilchards have also been reported from the Auckland Islands (51° 30′ S) by Waite (1916, p. 56), who collected them from shag vomits on Figure of Eight Island during the Australasian Antarctic Expedition of 1911-14. However, this record is suspect, because the maximum summer sea temperature at the Auckland Islands is 2 to 3° C less than the minimum temperature at which *Sardinops neopilchardus* is known to spawn (Blackburn 1960 and my data). The fish would therefore have to migrate long distances during summer to find water sufficiently warm for spawning. As such migrations are unknown, and the pilchard has not subsequently been reported from the area, inquiries were made at the Australian Museum for Waite's material. One small clupeoid fish was found which was labelled *Sardinops neopilchardus* from Figure of Eight Island, collected by the Australasian Antarctic Expedition. There are no data on the label, but it does state "ejected by shags". It therefore seems very likely that this specimen is one of Waite's *Amblygaster neopilchardus.* The specimen is in fact a species of *Sprattus* Girgensohn, probably *S. antipodum,* which is not in Waite's list of fishes from the Auckland Islands. I therefore regard the record of *Sardinops* from this area as very doubtful and have accordingly deleted it from the distribution map (Fig. 6).

Previous published work provides very little information on the seasonal distribution of the pilchard in New Zealand waters, but it does indicate that the fish has been most often recorded in summer. During the present study it was found that pilchards in the Marlborough Sounds-Tasman Bay area have a demersal phase during winter, when they seldom appear at the surface in large schools. This behaviour, and the probability of fewer opportunities occurring during winter for positive identification of fish schools, may account for the absence of winter records in other parts of the range of the species.

In the Marlborough Sounds-Tasman Bay area pilchards school at the surface in large numbers from October to March. The schools appear suddenly in Tasman Bay during October, and their occurrence is probably connected with an approaching spawning season. All age groups appear to be present in the area during winter, but in what quantity it was difficult to say. Echo traces showed large numbers of subsurface schools, but positive identification of such schools as pilchards was usually impossible. Among those which were occasionally identified were pilchards, sprats, and anchovies.

REPRODUCTION

DEFINITION OF MATURITY STAGES

Macroscopic changes in the appearance of gonads can be readily recorded in the field and have been widely used in maturity studies on clupeoid fishes. In the present investigation the stage of development of pilchard gonads was assessed with criteria similar to those adopted by the International Council for the Exploration of the Sea (Wood 1930) and some of those used in the South African pilchard investigation by Davies (1956) and Matthews (1964). The stages are:

Stage 1 — inactive
Stage 2 — inactive/active
Stage 3 — active
Stage 4 — active/ripe
Stage 5 — ripe
Stage 6 — ripe/running
Stage 7 — spent
Stage 8 — spent/inactive
Stage 9 — spent/inactive/active

The stages may be briefly defined as follows:

Stage 1. **Inactive:** Small ovaries, either immature or mature, less than half the body cavity length, narrow but firm, pale pink; no eggs visible. Testes flat and leaf-like, pink or transparent.

Stage 2. **Inactive/active:** Ovaries beginning to enlarge, slightly longer and up to 5 mm thick, dark pink. Testes beginning to thicken and elongate, white colour developing.

Stage 3. **Active:** Ovaries longer than one half body cavity length, noticeably thicker, and yellow with pigmented eggs. Testes elongated to over half body cavity length, thickened, opaque white, with wavy edges.

Stage 4. **Active/ripe:** Ovaries distended, almost completely filling body cavity, bright yellow, vascular; eggs discrete, becoming transparent at posterior end. Testes filling most of body cavity, opaque white, milkiness apparent at posterior end.

Stage 5. **Ripe:** Ovaries at maximum size, darker yellow and semi-transparent owing to even dispersal of ripe transparent eggs throughout gonads. Testes at maximum size, posterior half milky.

Stage 6. **Ripe/running:** The same as previous stage, but pressure on belly causes extrusion of eggs or milt.

Stage 7. **Spent:** Ovaries elongated, but flat, hollow, and bloodshot; no large eggs present, except occasionally a few in oviduct. Testes elongated, strap-like, and bloodshot.

Stage 8. **Spent/inactive:** Ovaries spent, but showing signs of recovery to **inactive** stage; shrinkage, firmer, less bloodshot, and pale pink. Testes similar.

Stage 9. **Spent/inactive/active:** Ovaries and testes still showing signs of having been recently spent, but recovering to **active** stage.

In the first year of observations the **inactive** and **inactive/active** stages were of necessity assigned to gonads of both immature (virgins) and mature (spawners) fish; this was unavoidable because the size of pilchards at first maturity was not then known. Moreover, some of the **inactive/active** fish may not have developed to full sexual maturity owing to the phenomenon of pseudomaturity (Davies 1956), where gonads of sexually immature fish enlarge and partly develop during the spawning season, but regress before spawning.

Although stage 9, **spent/inactive/active,** was included in the field key to gonad activity, no gonads in that condition were found or recognised. This was possibly due to the shortness of the spawning season: once a fish had spawned, the gonads apparently passed rapidly through the **spent** stage to the **spent/inactive** stage, in which condition they remained until active development recommenced.

SEASONAL ACTIVITY OF GONADS

The monthly and seasonal gonad activity is shown in Fig. 7. Gonads were staged in 24 samples of pilchards taken during the period January 1966 to February 1968 (1,169 males and 1,355 females). Although selective fishing methods probably excluded very large pilchards from the catches, it is

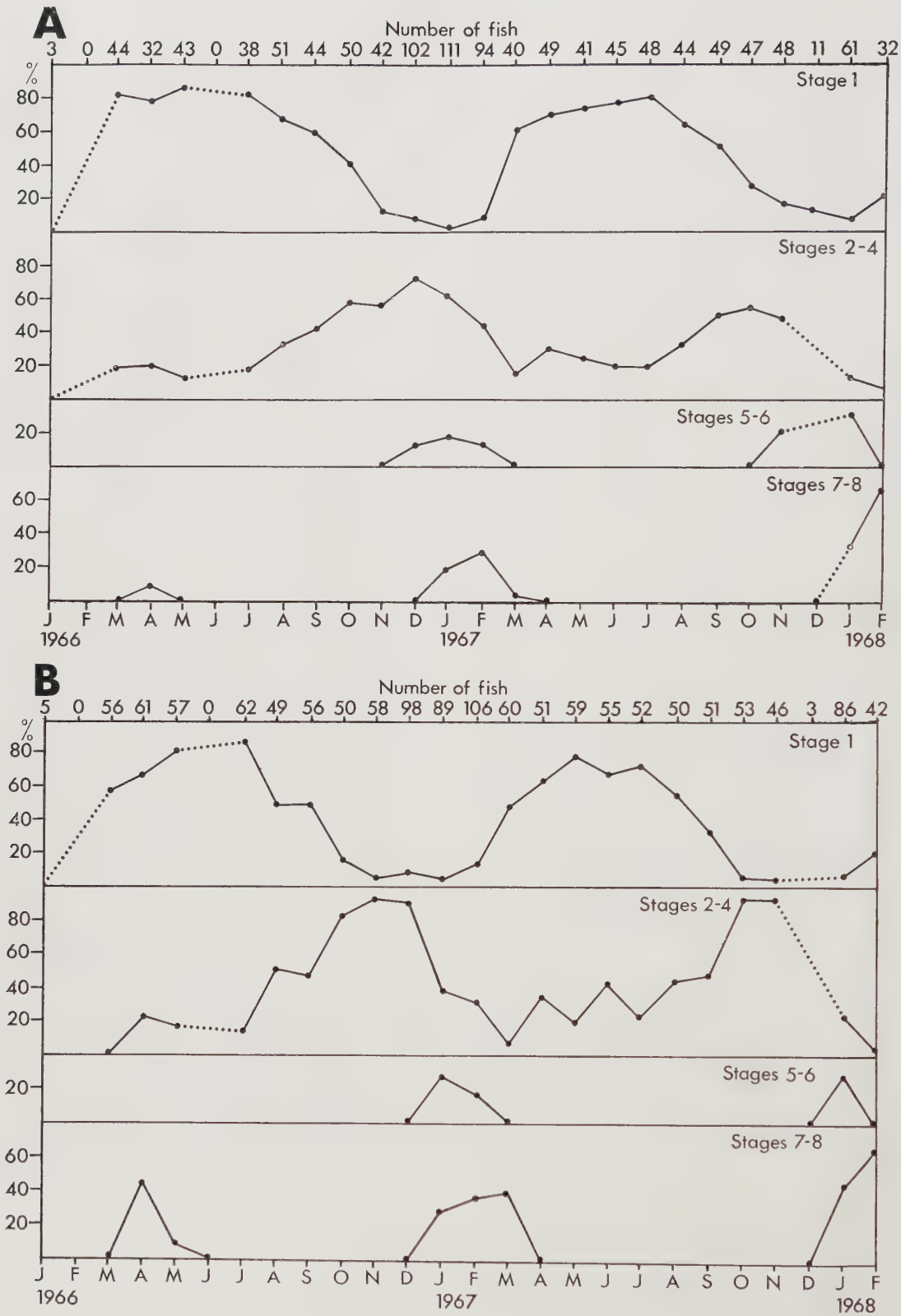


Fig. 7: A—Percentages of male pilchards in various stages of maturity from January 1966 to February 1968. B—Percentages of female pilchards in various stages of maturity from January 1966 to February 1968.

felt that as the data refer mainly to fish between 120 and 190 mm in body length (that is, 2- to 7-year-olds), the results are representative of seasonal reproductive development in the bulk of the pilchard population.

All reproductive data for the 2 years sampled are very similar, and there are no significant differences between male and female fish. The pattern of gonad activity during the 9 seasons sampled is:

1966: Summer - ripe and spent gonads.
Autumn — gonad activity low; inactive and spent stages.
Winter — gonad activity low.
Spring — gonad activity beginning and intensifying.

1967: Summer — gonad activity intense; both sexes ripe.
Autumn — gonad activity declining.
Winter — gonad activity very low.
Spring — gonads developing; ripe males.

1968: Summer — gonad activity intense; ripe/running female.

GONAD ACTIVITY AND SPAWNING

The results of the monthly assessment of gonad activity showed that in both years of sampling the season of greatest reproductive activity was summer. The autumn seasons were obviously post-spawning periods, when spent and declining gonads occurred. Both winters showed the lowest levels of reproductive activity, and each spring was a season of increasing development. Thus it appears that from November to February is the spawning season for pilchards in the Marlborough Sounds-Tasman Bay area and that January is the month of greatest reproductive activity.

Unfortunately, only one female fish with **ripe/running** gonads was collected during the investigation. Rarity of the final reproductive stage has been reported in many teleost studies (Clark 1934, Hickling 1945) and has been taken to indicate either migration of mature fish from the usual catch area or movement to deeper water within that area. Hickling's theory that the final spawning stage is sudden and short lived and that fish quickly shed the ripe eggs, with the ovary becoming spent, seems more likely to account for the missing stage in the present study. The occurrence of stages penultimate to **ripe/running** and recently spawned stages certainly suggested that spawning was either imminent or had just taken place within the study area. The occurrence of young (that is, a few hours old) pilchard eggs in the plankton also indicated that spawning fish had not left the locality.

SIZE AT FIRST MATURITY

Pilchards taken during the summer of 1966-67 were used to determine the size at which the fish first become sexually mature. Six hundred (307 males and 293 females) were examined. Because it was not possible to prove or disprove that pseudomaturity was taking place in small fish, the following procedure was adopted for the analysis:

Fish with **inactive** (stage 1) gonads during December, January, and February were regarded as immature and those with **active/ripe** (stage 4), **ripe** (stage 5), and **spent** (stage 7) gonads as mature. By discarding the intermediate stages, **inactive/active** and **active** (stages 2 and 3), any adolescent gonads developing to pseudomaturity should have been eliminated.

The smallest mature male found was 115 mm in body length. At length group 120 to 124 mm 65 percent of the males were mature, and at 135 to 139 mm, 90 to 100 percent were mature.

The smallest mature female was 118 mm in body length. At 120 to 124 mm 50 percent were mature, and at 135 to 139 mm all females were mature.

These results approximate to data for *Sardinops neopilchardus* in New South Wales waters given by Blackburn (1941), who found that most fish over 130 mm, and some smaller, had gonads in maturity stages 4 to 7, which showed that they had spawned or would do so during the season May to September. Pilchards from Victorian waters examined by Blackburn (1950) were mature at lengths of 70 to 105 mm. Such small mature fish were not found in the present study, but the number of small fish taken during the spawning season was negligible in any case.

GONAD WEIGHTS

Gonads from up to 20 large adult pilchards of each monthly sample were weighed to provide some accessory information on the reproductive

cycle. Because gonads from pilchards of several length groups (150 to 185 mm) were involved, use has been made of the maturity coefficient formula (Farran 1938, Nakai and Usami 1962), which expresses the relationship between length of fish and weight of gonads:

$$\text{kg (maturity coefficient)} = \frac{\text{gonad weight}}{\text{body length}^3} \times 10^4$$

The seasonal fluctuations in maturity coefficient, illustrated for male and female pilchards in Fig. 8, follow a pattern similar to that shown by previous data: maxima for both sexes occurred in January of both years and minima in the period May to June, which indicates a summer spawning and winter-spring recovery.

OVA DIAMETERS AND FECUNDITY

Pilchard ovaries at different stages of maturity were found to contain a complex of egg cells in various stages of development which had characteristic diameters and colours: small transparent cells of irregular shape less than 0.2 mm in diameter, rounded opaque cells 0.2 to 0.5 mm in diameter, and yellow or semi-opaque cells between 0.5 and 1.0 mm in diameter.

The smallest cells were undifferentiated and were present in gonads of all stages, including those which had recently spawned. The 0.2-0.5 mm type of cells showed the first signs of yolk, which was near the centre of each cell and was separated from the pellicle by a wide cytoplasmic gap. These cells were randomly scattered throughout the ovary and were more regular in shape than the smaller type. The largest type of cells must have been mature ova almost ready for spawning. They were spheroidal and filled with transparent yolk globules adpressed to one another so that the whole yolk had a segmented appearance (this segmentation was also observed in living pilchard eggs taken from the plankton). A single small oil globule was present in each cell at this phase of development.

The medium-sized and large ova were present only in maturing gonads (stages 2 to 5), and the diameter modes of the largest group progressed in size with the development of the gonads toward full maturity. The interval between these two groups of ova increased with advancing maturity.

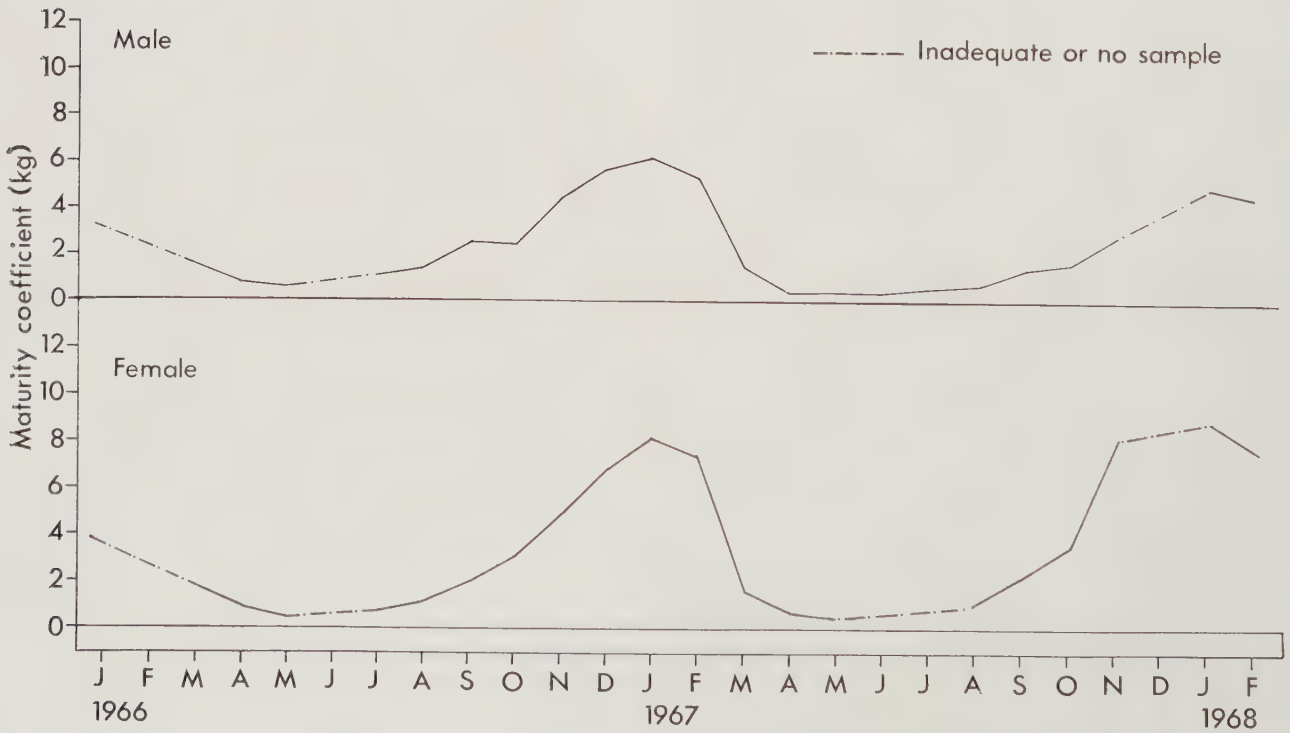


Fig. 8: Seasonal fluctuations in maturity coefficient for male and female pilchards, 1966-68.

The numbers of ova in the maturing groups were computed by dividing the total weight of the gonads by the weight of the ovary sample counted and multiplying this coefficient by the total number counted. The small cells below 0.2 mm were not counted, because they were regarded as immature and not likely to be spawned that year.

Table 2 shows that the total number of ova varies considerably with the fish length and that the largest fish have the most ova. The ratio of medium-sized ova to large ova is about 1:1. The correlation between numbers of ova and fish length conforms, as might be expected, with the findings for other *Sardinops* species (Davies 1956, MacGregor 1957).

TABLE 2: Typical numbers of medium-sized and large ova for maturing female pilchards

Body length (mm)	Weight (g)	Gonad weight (g)	Medium ova	Large ova	Total
145	39	2.3	8,900	16,400	25,300
159	50	3.5	32,300	27,500	59,800
162	54	4.3	26,700	26,500	53,200
173	64	4.4	24,900	32,300	57,200
177	70	5.6	25,900	37,200	63,100
181	72	6.1	30,900	36,500	67,400
187	91	7.2	48,300	44,500	92,800
192	101	8.1	51,100	45,600	96,700
204	114	8.6	62,900	47,500	110,400
213	124	9.7	61,900	46,600	108,500

Because stage 6 ovaries were not available for study, no firm conclusions can be drawn about the number of ova spawned in one season. However, if the medium-sized ova catch up in development with the larger ones, up to 110,400 ova could be spawned by a single fish at one time. Nevertheless, both large and medium-sized groups of ova are unlikely to mature simultaneously without overcrowding the ovary. Successive maturation of ova and their intermittent release would, however, allow for such a large number of eggs to be produced over a whole spawning season. Although fractional spawning is apparently characteristic of many clupeids (see Ivanova 1949, Naumov 1956, Reintjes 1961), it has not yet been recorded in *Sardinops*. Besides, the occurrence of several sizes of ova in an ovary does not necessarily indicate fractional spawning, for in many fishes the smallest groups of ova are resorbed after spawning (Nikolsky 1963, Combs 1969).

The maximum recorded number of 110,400 ova for the New Zealand pilchard is comparable with estimates of total ova for large South African pilchards (110,388: Davies 1956) and Californian sardines (104,340: Clark 1934).

EVIDENCE OF SPAWNING FROM THE PLANKTON

Pilchard Eggs

Descriptions of pilchard eggs and larvae are given on pages 30 to 45.

Regular monthly plankton sampling began in March 1966, and pilchard eggs were not found until December of that year, when they were collected at in-shore stations in Tasman Bay. The number of pilchard eggs reached a peak in January 1967, when they were found in both the Marlborough Sounds and Tasman Bay. Eggs were much less abundant in February and were not recorded again until late in the following spring.

Small numbers of eggs were found in Tasman Bay in November 1967, a maximum in December, and decreasing numbers in January-February 1968. Regular plankton sampling ceased after February 1968, but during the following November and January 14 samples were obtained from Tasman Bay; pilchard eggs were absent from the November samples, but present in those collected during late January.

Pilchard Larvae

In 1966 pilchard larvae were first recorded in March and in April-May, when they were found in predator-fish stomachs and in the plankton. No larvae were collected during winter or spring, but they reappeared in December and their numbers steadily increased to a maximum in February and then fell off through autumn to a single record in June 1967. Larvae were not recorded again until November of that year, after which they occurred each month throughout the summer of 1967-68.

The occurrence of pilchard eggs in the plankton only during summer, and of larvae during summer and autumn, thus confirmed other evidence that the breeding season extends from November to February.

LOCATION OF SPAWNING GROUNDS

The presence of early-stage pilchard eggs at most stations indicated that spawning takes place throughout the Marlborough Sounds-Tasman Bay area. The main concentration of eggs seemed to be

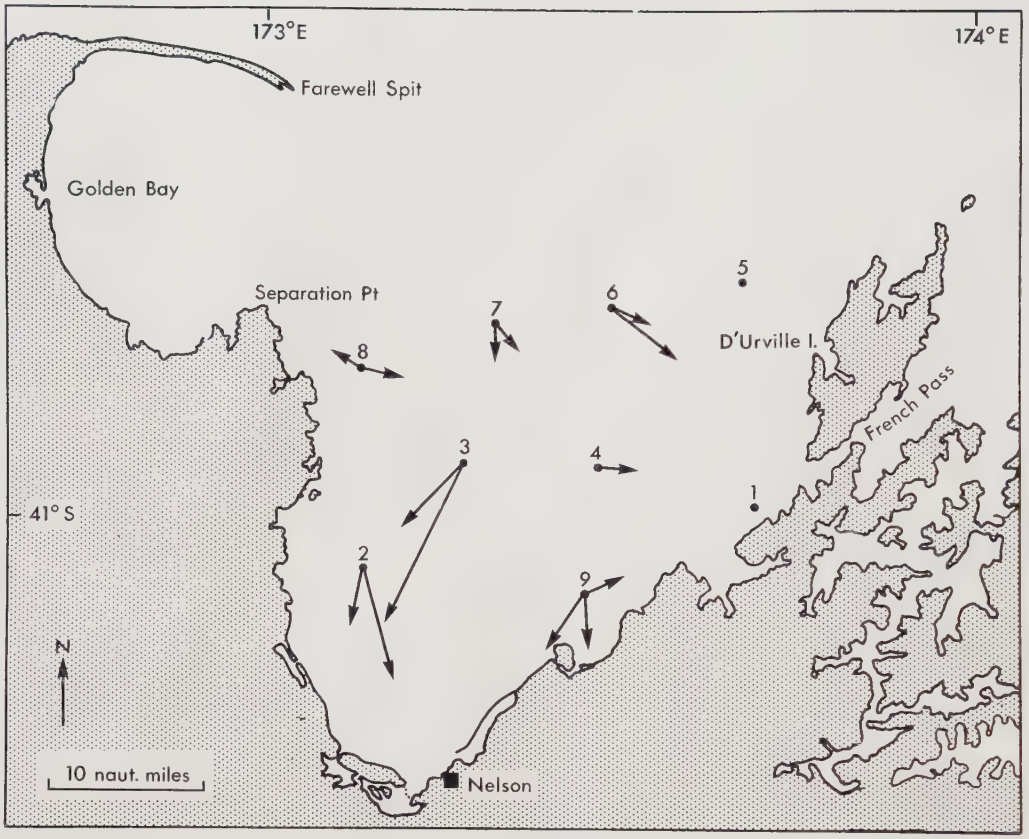


Fig. 9: Release points of drift cards in Tasman Bay. Arrows indicate direction of shortest tracks between release and recovery positions. Arrow lengths are proportional to the number of cards recovered in that direction.

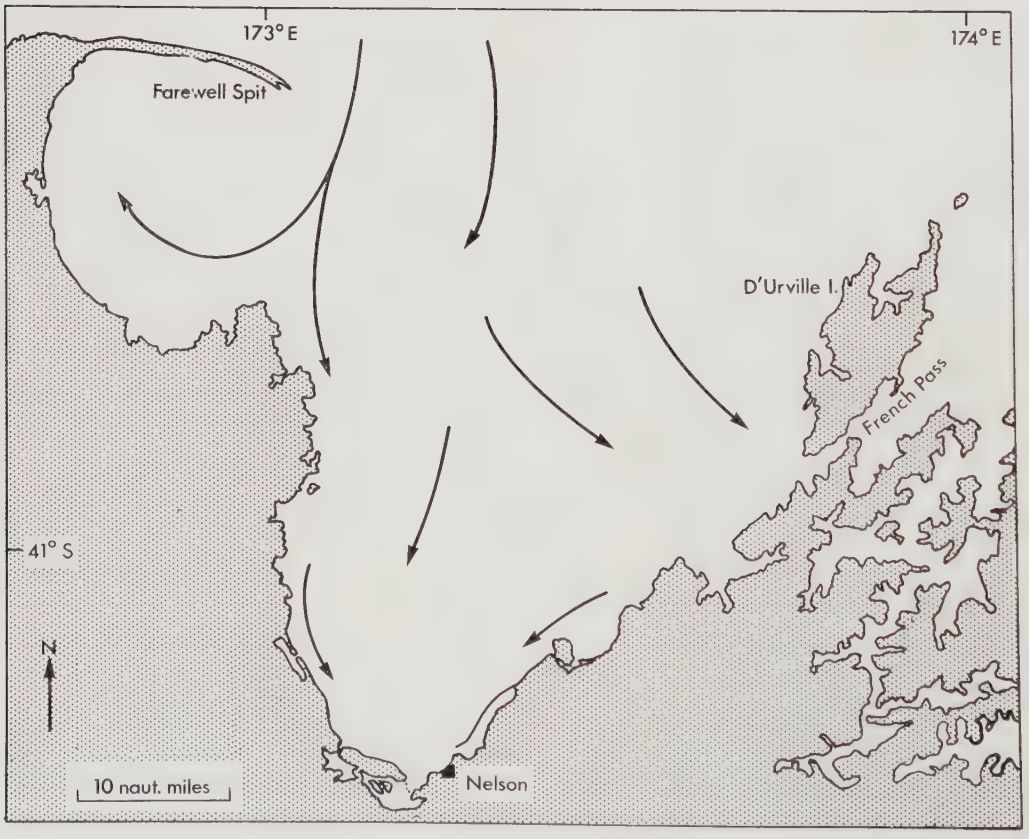


Fig. 10: Surface water movements in Tasman Bay as indicated by drift card recoveries.

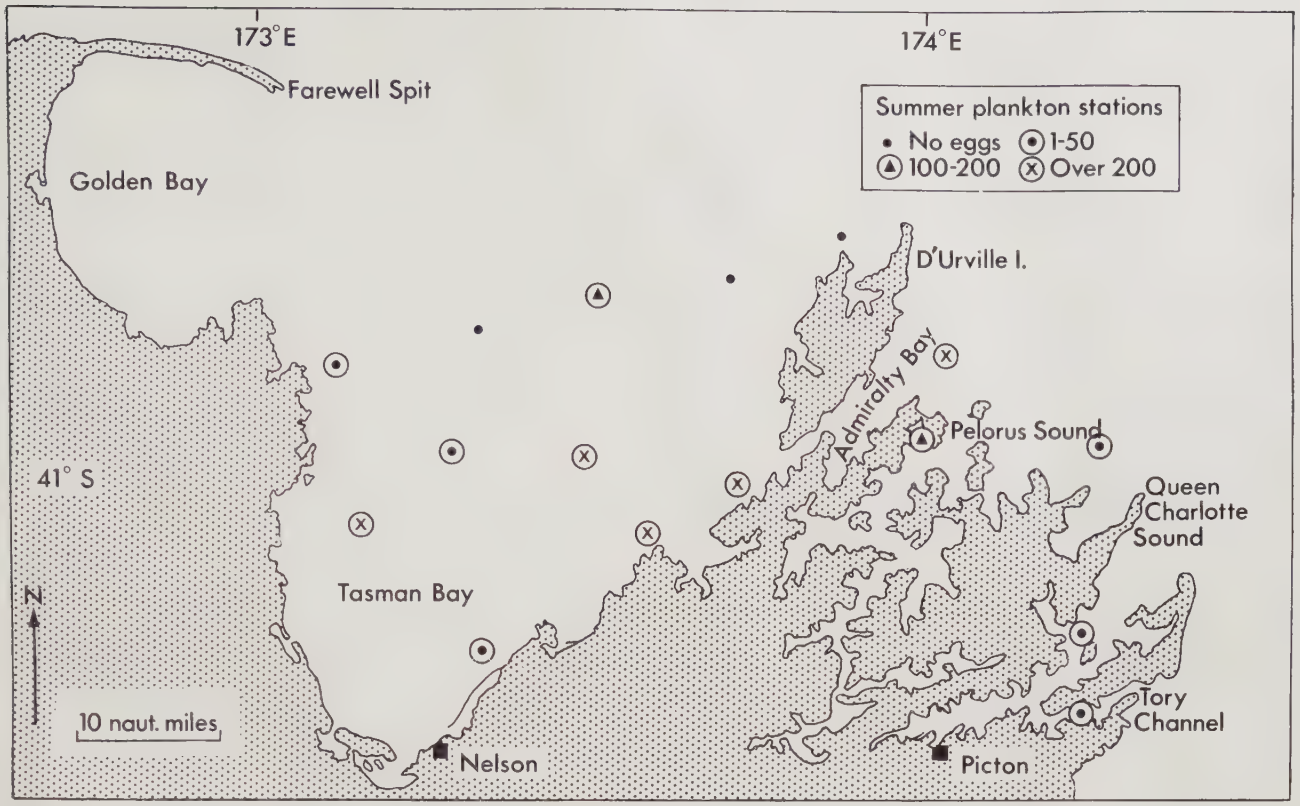


Fig. 11: The abundance of pilchard eggs (all hauls combined) in the plankton at different stations in the Marlborough Sounds and Tasman Bay, 1966-68.

in Tasman Bay. However, the total number of eggs collected in both spawning seasons was small compared with the large number of pilchard shoals seen in the region, and it was considered possible that the eggs were either being swept out of Tasman Bay by currents or that more extensive spawning was taking place outside the area and that only a small proportion of eggs was being carried into the bay by water movements.

To test these possibilities a preliminary investigation of summer water movements in Tasman Bay was carried out in December-January 1968 with drift cards. As the pilchard egg is buoyant throughout development and floats near the surface, it was considered that the surface water movement as shown by drift card recoveries might indicate the movement of eggs in the bay. Twenty plastic-covered drift cards (Olson 1951) were released at each of nine stations throughout the bay (Fig. 9). Forty-nine (27 percent) of the 180 released were recovered from the coastline around the perimeter of the bay. A plot of the shortest distances from release point to recovery point shows that the principal movement of surface currents during the period was landward. Thus non-motile pelagic eggs drifting in the bay would have been gradually distributed landward.

The drift card tracks indicate a westerly movement of surface water from northern Tasman Bay into Golden Bay, a south-east to south-west movement along the western coast of the bay, and an east-south-easterly flow from the middle and outer parts of the bay toward French Pass (Fig. 10). A south-westward flowing current appears to move close in shore along the south-eastern coastline toward Nelson. These results support Heath's (1969) discussion on the circulation in Golden and Tasman Bays based on other drift card data and geological evidence. According to Heath, the general circulation consists of a clockwise gyre in Golden Bay and a counterclockwise flow in southern Tasman Bay, opposed by a south-flowing current close in shore on the eastern shore of Tasman Bay.

The general pattern of movement of water toward the southern and eastern shores of the bay thus makes it appear unlikely that planktonic fish eggs would be swept out of the area during summer. The occurrence of very young (a few hours

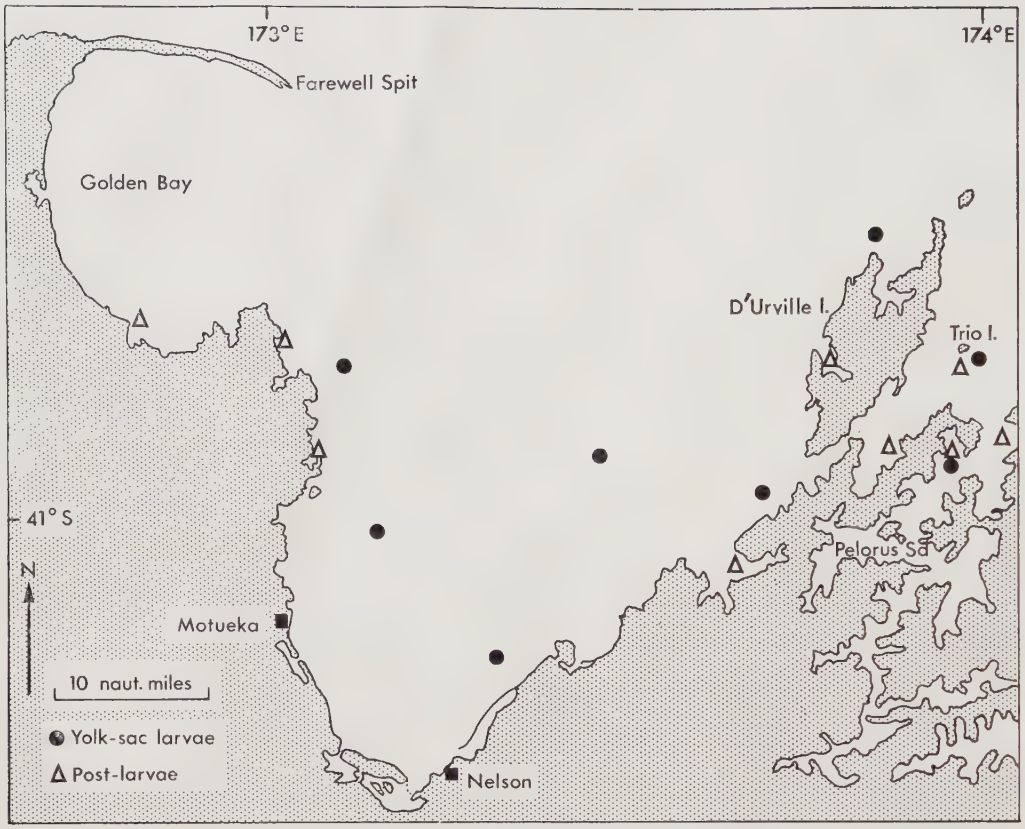


Fig. 12: The distribution of pilchard larvae in Tasman Bay, 1966-68.

old) pilchard eggs in Tasman Bay, and the discovery that only 2 to 3 days elapsed between fertilisation and hatching, precluded the consideration that eggs were being carried into the area from a distant spawning ground. Moreover, the fact that no pilchard larvae were taken at the stations across the bay entrance suggested that those collected from in-shore stations had developed within the bay. A comparison between the location of pilchard eggs in Tasman Bay for both years combined, the distribution of larvae for the same period (Figs. 11 and 12), and the proposed surface current system suggest that eggs and young larvae developing near the middle of the bay could be swept by currents to the numerous sheltered inlets around the adjacent coastline, or through French Pass into the Marlborough Sounds, where they would eventually grow into post-larvae.

Blackburn (1949) concluded that in New South Wales waters pilchard larvae move in shore from the spawning areas and remain in inlets until they are over 1 year old, when they congregate into shoals and move back to the open sea. The reason for these early in-shore movements is not known, but an estuarine habitat could be necessary for the start of gonadogenesis (Combs 1969).

These suggestions must be regarded as only preliminary, because the collections of New Zealand

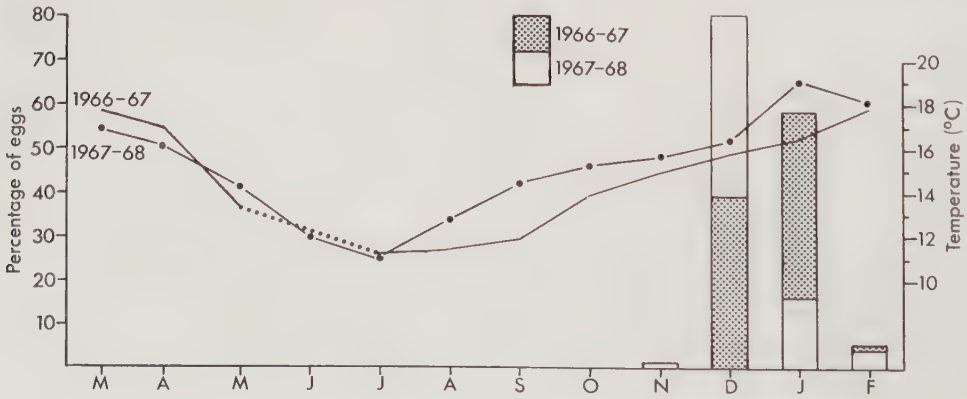


Fig. 13: The occurrence of pilchard eggs in the plankton of the Marlborough Sounds and Tasman Bay in relation to seasons and sea surface temperature.

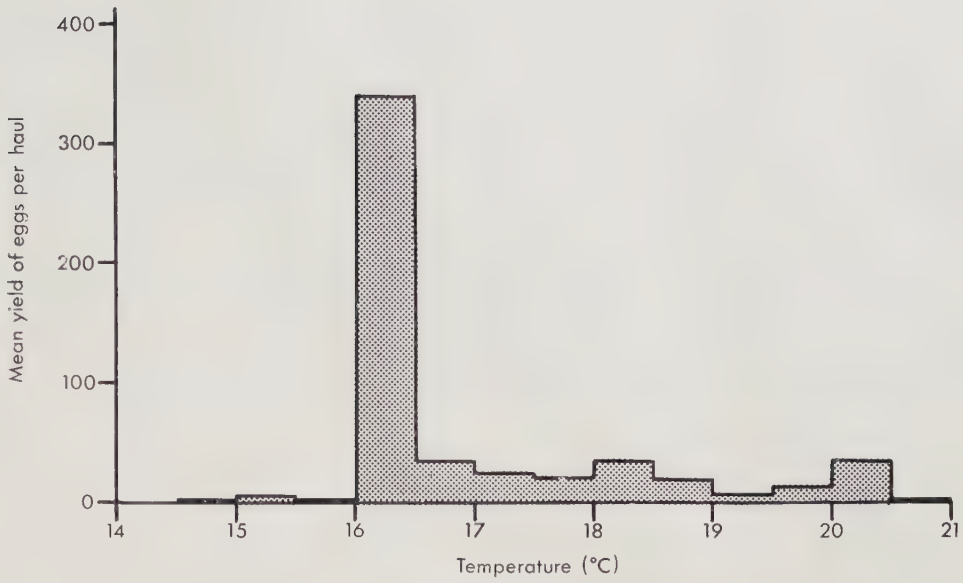


Fig. 14: The mean yield of pilchard eggs per plankton haul in relation to surface temperature.

pilchard eggs and larvae were inadequate for accurate quantitative studies on distribution.

SPAWNING IN RELATION TO TEMPERATURE

Temperature has been shown to be important in controlling the reproductive rhythm of seasonal spawners (Hoar 1957), and in many species of fish the breeding period is limited by apparently constant maximum and/or minimum temperatures (Orton 1920).

The graph relating to the seasonal occurrence of pilchard eggs in the plankton (Fig. 13) shows that spawning takes place with rising temperatures. Pilchard eggs were recorded within the surface temperature range of 14.7° to 20.9° C, but most samples containing eggs were taken between 16.0° and 16.4° C. This is illustrated in Fig. 14, in which the data have been processed by calculating the mean yield of eggs per haul for 0.5° C intervals. Ideally, these data should be treated in terms of the frequency of occurrence at certain levels of abundance, which takes into consideration both frequency and the order of numbers (Stander 1963). The total number of eggs found in the present investigation was, however, considered too small to be subjected to a more refined analysis. Furthermore, the fact that temperature profiles were not being measured during the peak spawning months meant that the water temperature at actual sampling depth was not being recorded, and as the profiles for February 1968 show (Figs. 15 and 16), there is considerable variation between the surface and the 30-m level in the spawning grounds.

A more detailed and quantitative study of the occurrence and abundance of pilchard eggs in relation to accurately monitored seasonal sea temperature profiles is required to assess the true significance of this apparent optimum relationship. However, it appears likely that the optimum temperature for spawning lies near to 16.0° C, for studies on other species of *Sardinops* have shown similar optimum temperatures.

For example, Davies (1956) found that the largest numbers of South African pilchard eggs were taken between 14° and 16° C and concluded that the threshold for major spawning activity was 13° C. Pilchards in South West African waters, however, spawn over a wider range of surface temperatures (10.9° to 22.6° C) and apparently have narrow winter and wide summer optima of 12.2° to 12.9° C and 11.75° to 22° C respectively (Stander 1963).

Eggs of the Californian sardine have been found at temperatures between 10° and 24°C, and according to Tibby (1937), the optimum temperature for spawning is between 15° and 18° C. Ahlstrom (1954) found, however, that most of the spawning off California occurred within the range of 12.5° to 16.5° C. The Japanese sardine is known to spawn between 11.1° and 19.1° C (Nakai and

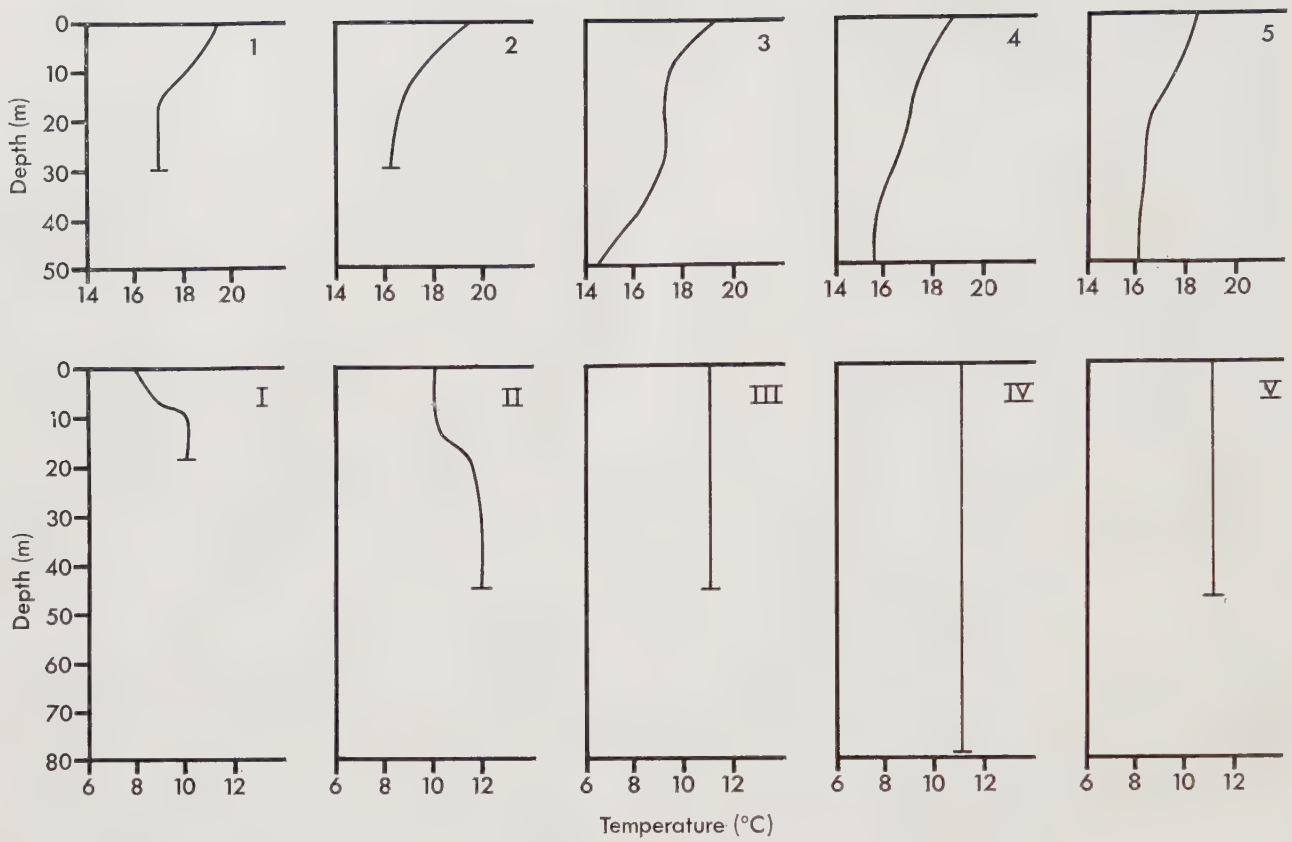


Fig. 15: Temperature profiles for Tasman Bay. 1-5, February. I-V, July (July data from New Zealand Marine Department records).

Hattori 1962), and the optimum temperature range is thought to be 13° to 16° C.

In Australian waters *Sardinops neopilchardus* breeds within the temperature range 14° to 21° C (Blackburn 1960); unfortunately, there are no data available on optimum breeding temperatures in that region. Blackburn has shown, however, that surface temperature appears to determine the distribution of spawning pilchards: on the east coast of Australia the centre of spawning activity moves northward following the 21° C surface isotherm during February to August and southward with the 14° C isotherm during August to February. In the region between the August 14° C isotherm and the February 21° C isotherm the water is warm enough for year-round spawning.

A similar situation in New Zealand, with a southern spring-summer spawning season and a northern year-round breeding period, was postulated by Blackburn (1960). A late spring-summer season for pilchards in the central New Zealand region is confirmed by the present study, and a similar spawning season in the southern part of the country is indicated by other authors (Sherrin 1886, Thomson 1892, Graham 1939). Records of pilchard larvae from Spirits Bay in September (Regan 1916) and the Bay of Islands, Tutukaka, and Ngunguru Bay in January (my collection) and of eggs in the plankton of the Hauraki Gulf

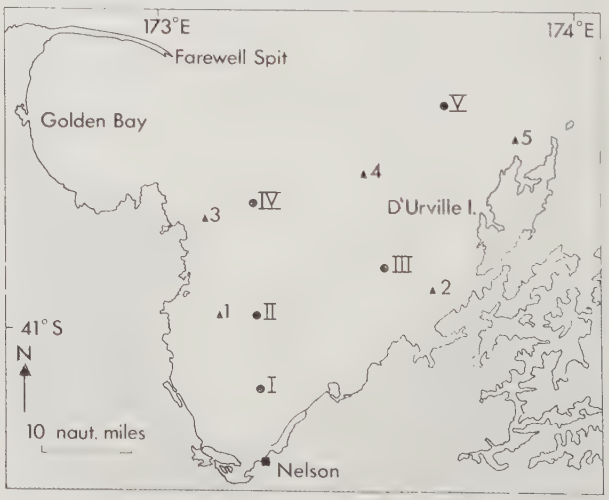


Fig. 16: Temperature profile stations in Tasman Bay. 1-5, February 1968 (summer). I-V, July 1969 (winter).

in November-December (Cassie 1956) and the Bay of Islands in August (my collection) indicate that breeding takes place throughout the year in northern waters. In this northern area the winter temperature minimum is about 14° C and may be warm enough for year-round spawning. If this isotherm is near the minimum temperature necessary for the spawning of pilchards in New Zealand waters, a southward movement of spawning activity similar to the east Australian one could take place during spring and summer as the isotherm moves southward (Fig. 6).

DEVELOPMENT OF EGGS AND LARVAE

EGGS

Spawned eggs of the various *Sardinops* species in different parts of the world are very similar in appearance and size, and their morphological characteristics throughout development have mostly been well described and figured (Miller 1952 and references therein, Davies 1954, Nakai 1962). However, the only description of fertilised eggs of *S. neopilchardus* is that by Dakin and Colefax (1934) of eggs collected from the plankton off Sydney Heads, Australia. Dakin and Colefax briefly described the egg's main distinguishing features and gave an egg diameter range of 1.27 to 1.50 mm and a mean diameter of 1.44 mm. The only record of pilchard eggs in New Zealand waters is by Cassie (1956), who recorded 20 eggs with a mean diameter of 1.43 mm from the Hauraki Gulf.

In the absence of detailed information on the embryology and the duration of development of Australian and New Zealand pilchard eggs, each sample taken from the plankton during the present study was examined closely. During the first season no pilchards in full spawning condition were collected, so that artificial fertilisation and accurate studies of rates of development could not be attempted. A sequence of developmental stages of eggs from a few hours old to hatching was, however, built up from the plankton samples. In the second year artificially raised eggs were followed through to hatching.

Description of Egg

The fertilised egg is spherical, with a diameter range of 1.32 to 1.70 mm and a mean diameter of 1.53 mm. The vitelline membrane is smooth and transparent, and there is a wide (0.60 to 0.85 mm) perivitelline space. The yolk is small (0.71 to 0.83 mm during first cleavages) and distinctly segmented. At the opposite end of the yolk to the blastodermal cap is a single oil globule 0.15 to 0.17 mm in diameter. The egg is buoyant throughout development and floats near the surface with the oil globule uppermost and the embryo hanging upside down under the yolk.

DEVELOPMENTAL STAGES OF EGGS

The development of the egg from spawning to hatching was separated into 12 morphological stages based partly on those used in studies of the Californian sardine (Ahlstrom 1950) and the Cornish pilchard (Cushing 1957). A brief description of the main features of each stage is given below. This study was designed to facilitate ready identification of the egg at any stage of development rather than to provide a detailed account of the embryology itself. The stages are illustrated in Figs. 17 to 21.

Stage 1: Unfertilised Egg, No Cleavage (Fig.17A)

Eggs in this stage are either unfertilised or so recently fertilised that cleavage has not started, though there is usually some condensation of protoplasm at the animal pole, which eventually forms a single cell protruding above the curve of the yolk. The eggs are characteristically small, with a diameter of about 1 mm. This small size is due to the perivitelline space not having developed much. (As the fertilised egg develops, the perivitelline space forms by expansion of the vitelline membrane through absorption of water (Miller 1952); this "water hardening" process takes about 10 to 12 hours in the New Zealand pilchard.)

Stage 2: Cleavage (Fig. 17B and C)

This stage is one of cleavage, beginning with a meroblastic and meridional division and passing through successive divisions to the 128-cell stage. The first division of the single cell results in two cells of equal size, which also divide meridionally, but at right angles to the first division. The four blastomeres then divide vertically, parallel to the first cleavage, to form an 8-celled stage. After a further vertical cleavage to form 16 cells, the successive blastomeres become less regular in shape, though they are still large and prominent.

Stage 3: Cell Multiplication (Fig. 17D)

With repeated cleavages, the cells become smaller and the blastodermal cap, though not increasing noticeably in size, assumes the shape of a

smooth lenticular bowl. This is a period of cell multiplication rather than one of growth.

Stage 4: Blastula Formation (Fig. 18A)

The blastocoele forms during this stage when the blastodermal cap separates from the underlying periblast. The blastocoele develops eccentrically, which leaves the blastoderm distinctly thicker on one side; this thickening subsequently develops into the axial portion of the embryo proper. The marginal cells of the blastoderm divide, and a germ ring begins to extend around the blastodisc. By the end of this stage of blastula formation, the germ ring has completely surrounded the margin of the blastoderm and covers about one-third of the yolk.

Stage 5: Gastrula Formation (Fig. 18B)

Ingrowth of the anterior end of the blastoderm continues and is accompanied by involution and epiboly at the posterior end. At the beginning of stage 5 the embryonic shield, though rudimentary, is visible, particularly when viewed edge on. At

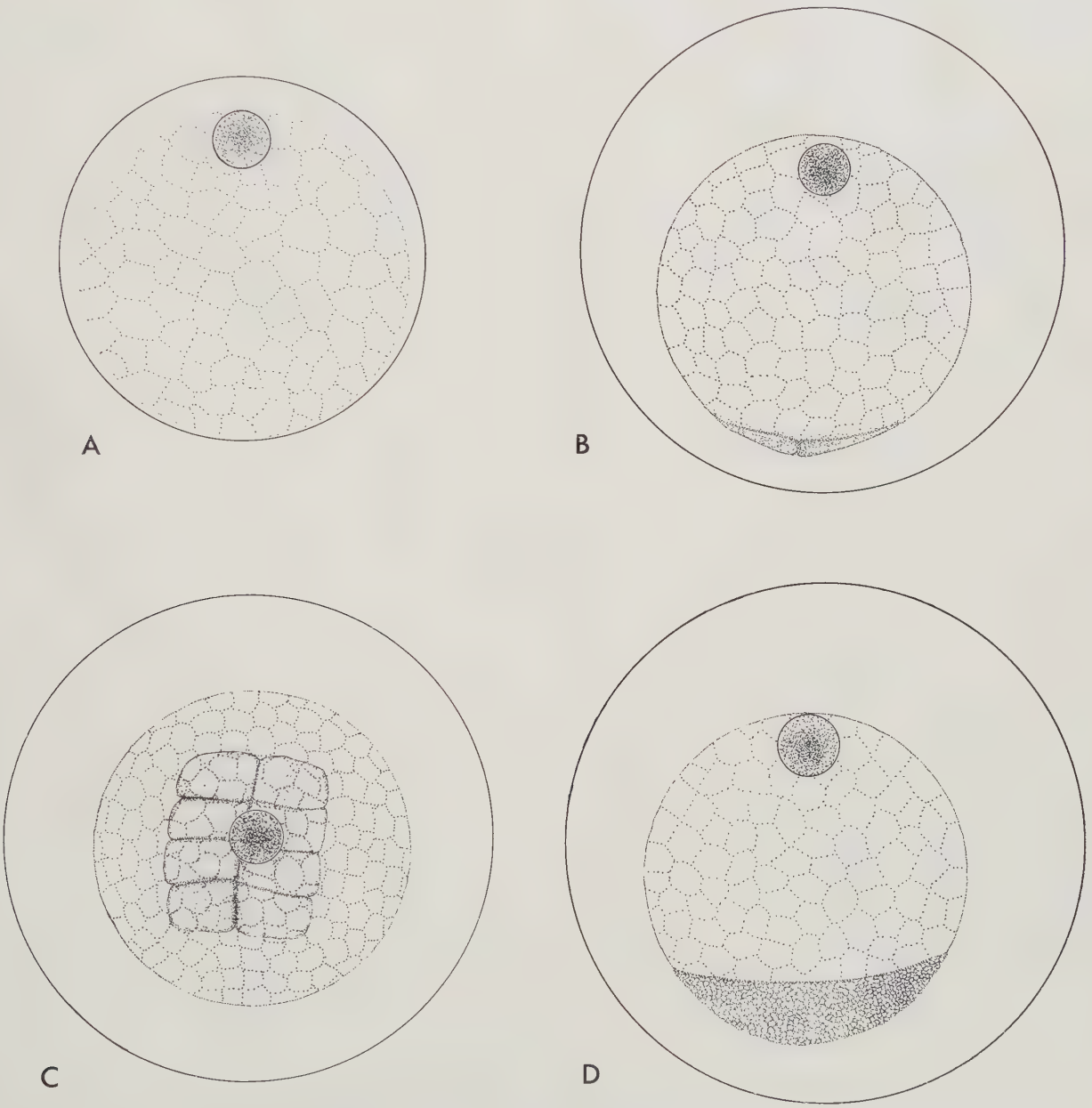


Fig. 17: Developmental stages of pilchard eggs. A—Stage 1, lateral view. B—Stage 2, lateral view. C—Stage 2 (later), dorsal view. D—Stage 3, lateral view.

the end of this stage the embryonic axis is distinctly visible along the median line of the embryonic shield, and as epiboly proceeds the gastrula encloses about four-fifths of the yolk.

Stage 6: Neurula Formation (Fig. 18C and D)

The cells of the germ ring close in from all sides at the posterior pole of the developing embryo and leave only a small opening, the blastopore, which

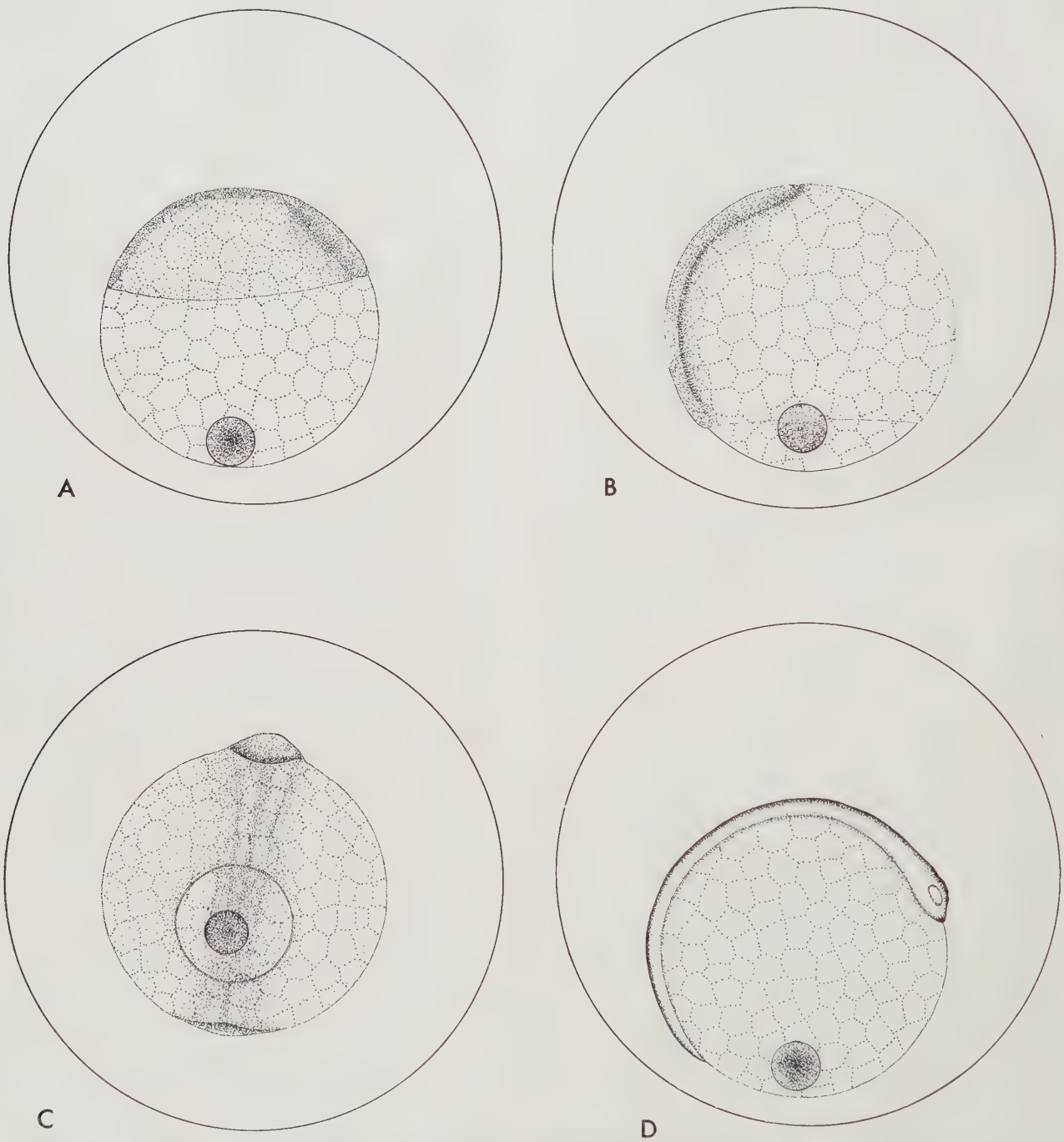


Fig. 18: Developmental stages of pilchard eggs. (This and the following figures of eggs are illustrated with the oil globule lowermost to enable clearer interpretation of the developing embryo. Normally, the pilchard egg floats with the oil globule uppermost as in Fig. 17.) A—Stage 4, lateral view. B—Stage 5, lateral view. C—Stage 6 (early), ventral view. D—Stage 6 (late), lateral view.

itself becomes closed during this stage. The embryonic keel thickens, particularly in the cephalic region, and the tail remains scarcely differentiated from the surrounding tissue. The optic vesicles are present, but rudimentary by the end of stage 6. The oil globule at the vegetative pole is located off-centre of the polar axis and lies close to the tail area at the time of blastopore closure.

Stage 7: Cell Differentiation (Fig. 19A)

During this stage the optic vesicles enlarge and the main divisions of the brain become distinguishable when viewed from above. The embryo lengthens and extends about two-thirds of the way around the yolk, but the tail does not quite reach the level of the oil globule and remains flush with the surface of the yolk. A few somites become apparent about the middle of the embryo, and by the end of this stage the tail becomes slightly swollen at the tip, and the lenses are visible in the eyes.

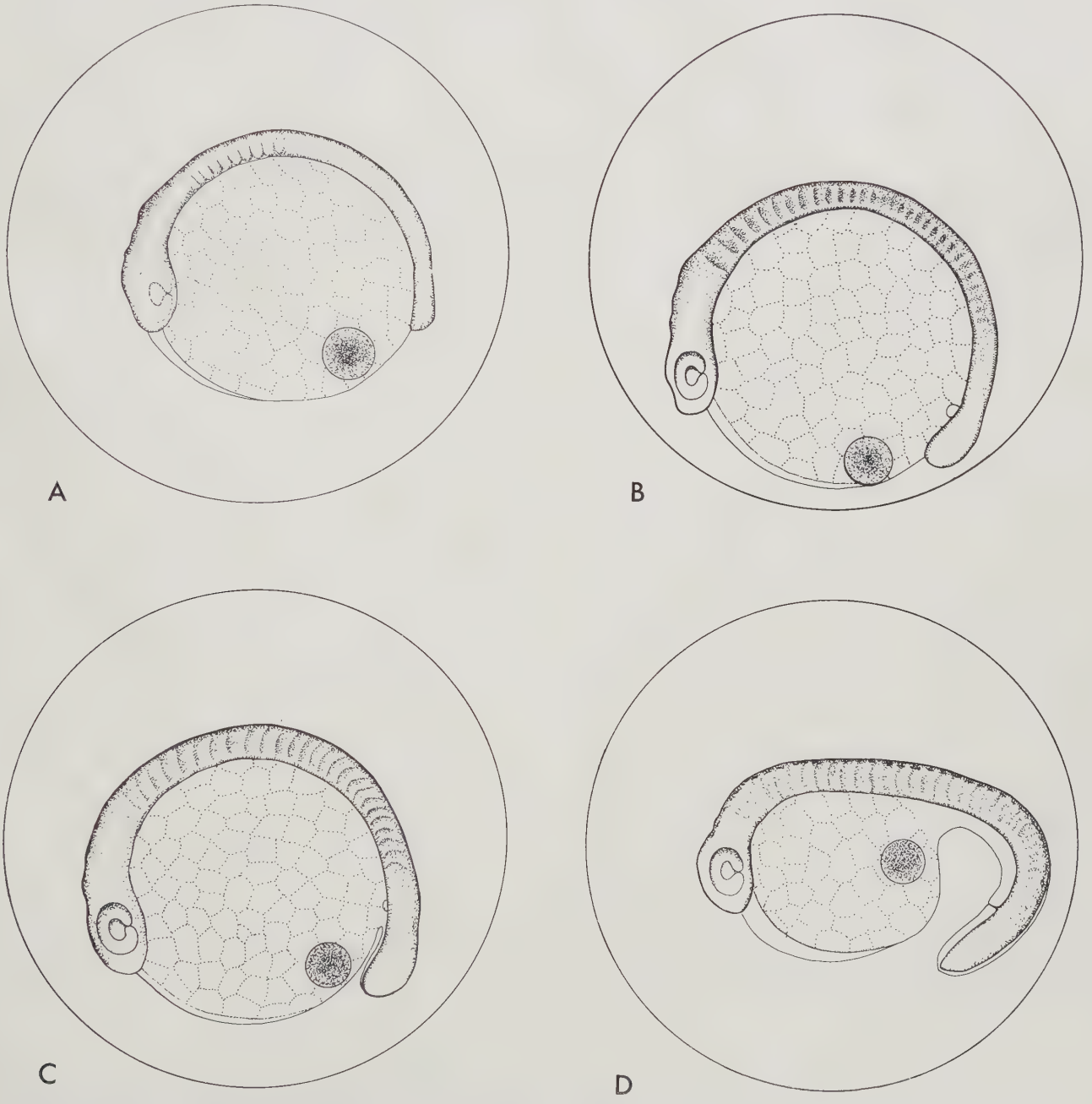


Fig. 19: Developmental stages of pilchard eggs. A—Stage 7, lateral view. B—Stage 8 (early), lateral view. C—Stage 8 (late), lateral view. D—Stage 9, lateral view.

Stage 8: Tail Separation (Fig. 19B and C)

The tail separates from the yolk during stage 8, and the free portion becomes about equal in length to the head of the embryo and extends up to, but not beyond, the oil globule. Kupffer's vesicle appears anterior to the tip of the tail, and distinct somites extend along most of the body apart from near the base of the tail. The fin fold is apparent on the ventral edge of the tail. Throughout this stage and the remaining stages there is further growth and organo-differentiation. The eye, olfactory placode, and main divisions of the brain become well defined, the auditory capsules appear, the pericardial cavity becomes evident either side of the mid-brain, and the intestine appears.

Stage 9: Tail Lengthening (Fig. 19D)

This stage and subsequent stages are characterised mainly by the degree of development of the tail, which provides the most easily recognisable morphological change throughout the remainder of embryonic growth. During stage 9 the length of tail separated from the yolk increases from an amount just greater than head length to about one-third of the body length. The fin fold is slightly more conspicuous on the ventral margin of the tail, but is still less than one-quarter of the body depth. The positions of the intestine along the ventral edge, and the anus toward the base of the tail, are evident. The posterior position of the anus is a clupeoid characteristic most useful in identification. The dorsal fin fold is discernible near the tip of the tail. A double row of small, elongated, dendritic melanophores develops along the dorsal edge of the embryo; near the head and in the middle of the embryo the melanophores are close and may link up, but they are more widely separated toward the tail. Further somites differentiate along the tail just above the anus.

As the tail lifts further off the yolk sac and starts to bend to one side of the yolk the middle portion of the body begins to straighten. The head remains curved around the yolk-sac membrane, and as the amount of yolk decreases, a conspicuous space develops within the sac, under the head.

Stage 10: Tail Bending (Fig. 20A)

At the beginning of stage 10 the posterior one-third of the body has lifted from the yolk sac, and the tail has bent further to one side of the yolk. The body cavity has extended under the trunk and separates the gut from the yolk sac. During this stage the heart begins beating, and the first contractions of somatic muscle take place anterior to the ventral flexure of the tail. The frequency of contractions and relaxations is low and produces only a slight bending of the body axis. The fin folds are from one-quarter to half as deep as the body, and the dorsal fold, though narrower than the ventral one, is now evident along three-quarters of the body. The embryo straightens further in the trunk region, and the tip of the tail loses its rounded appearance and becomes pointed. Either side of the dorsal fin fold the melanophores extend anteriorly to directly above the heart; there is no pigment in the head region. By the end of this stage the free portion of the tail is bent at an angle of about 45° to the trunk of the embryo.

Stage 11: Tail Parallel with Trunk (Fig. 20B)

The change in the plane of orientation of the embryo begun in stage 10 is completed in this stage by the tail flexing laterally and upward to lie parallel to the now straightened trunk; only the head remains curved around the yolk. At the end of this stage the posterior tip of the fin fold is level with the hindbrain, and the folds are about twice the depth of the body. Somites develop posterior to the anus, and neuromast organs appear on the flanks of the trunk and tail. Body movements increase in frequency and are not restricted to the pre-anal somites.

Stage 12: Embryo Active (Fig. 20C)

During this stage, which ends with hatching, there is a noticeable lengthening of the tail from level with the hindbrain until it overlaps the head for a considerable distance. The free posterior portion of the body becomes longer than the remaining anterior end, which is still attached to the yolk sac. The head is still curved over the yolk sac at hatching. Melanophores appear on the head and laterally between the anus and the tip of the tail. The embryo is very active, and intrachorional somersaulting eventually results in rupture of the chorion and escape of the larva.

The main identifying features of each stage of development are:

Stage	Diagnosis
1	Small perivitelline space; no cleavage.
2	First cleavages, to 128-cell morula.
3	Blastodermal cells very small; cell multiplication.
4	Germ ring formation; blastoderm covers one-third yolk.
5	Embryonic shield visible; blastoderm covers four-fifths yolk.
6	Blastopore closes; optic vesicles visible.
7	Swollen tail of embryo almost reaches oil globule; somites visible.
8	Tail separates from yolk, extends to oil globule, but not beyond.
9	Free tail one-third body length; melanophores appear dorsally.
10	Tail bent at 45° angle to trunk; fin folds one-third depth of body.
11	Tail parallel with trunk; tip level with hindbrain.
12	Tail overlaps head; embryo active. (Hatching imminent.)

DURATION OF DEVELOPMENT

In January 1968 eggs were stripped from a ripe female pilchard and fertilised from macerated testes from an almost-ripe male fish. Development was then followed through to hatching aboard the research vessel. This provided positive identification of the pilchard egg at each of its embryological stages.

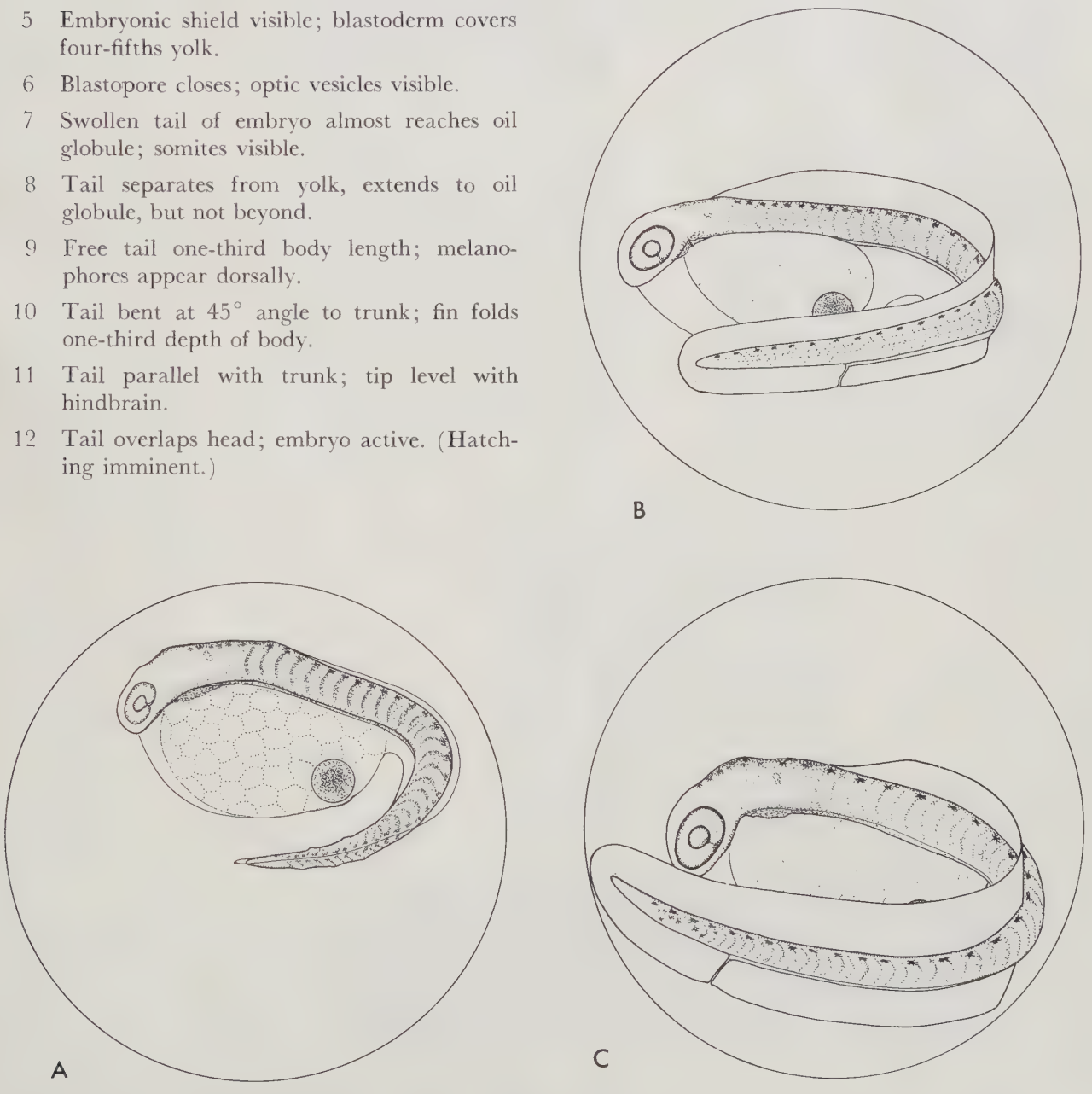


Fig. 20: Developmental stages of pilchard eggs. A—Stage 10, lateral view. B—Stage 11, lateral view. C—Stage 12, lateral view.

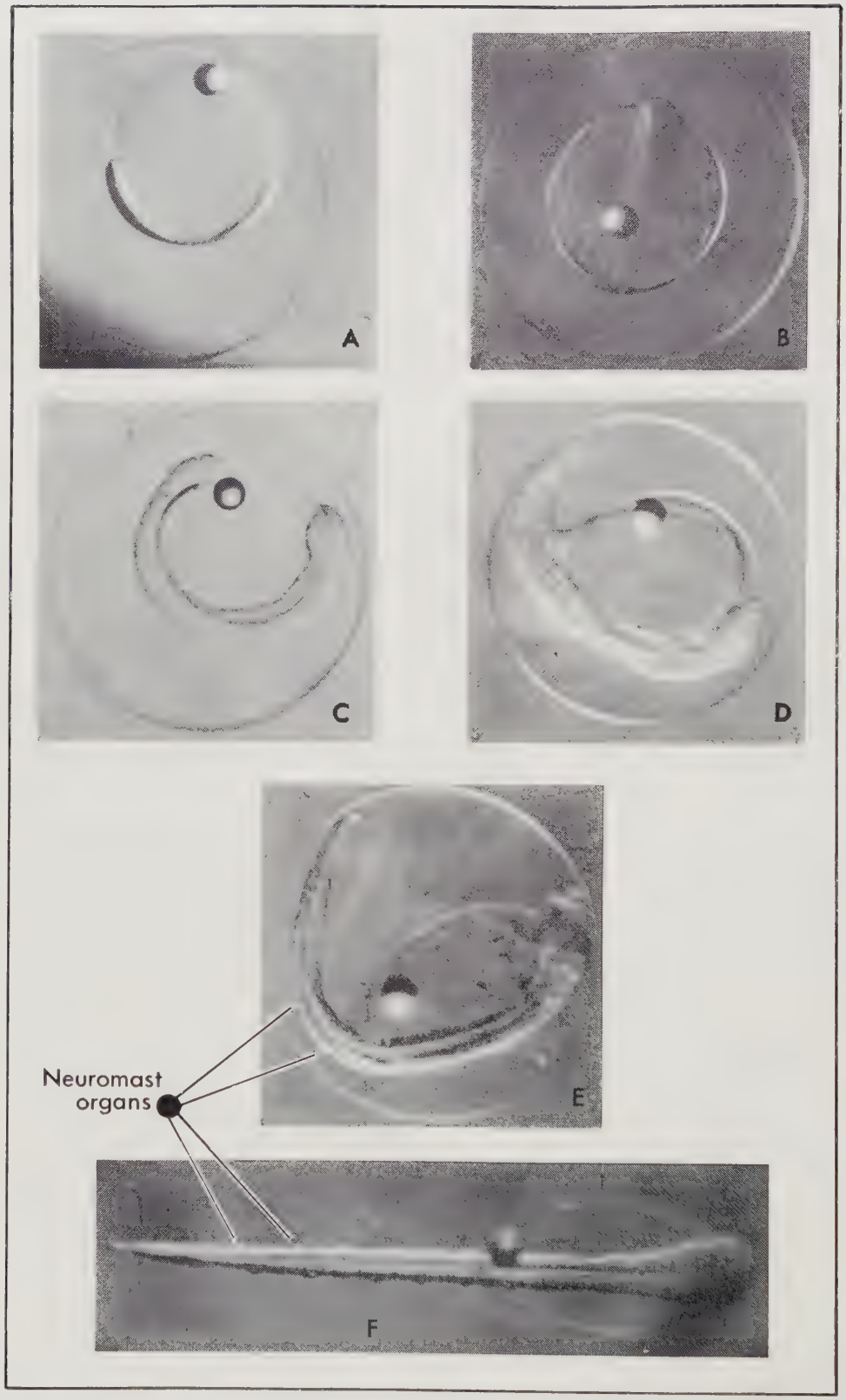


Fig. 21: Eggs and yolk-sac larva of the pilchard, reared from a collection of stage 3 eggs taken from the plankton in Golden Bay, 29 January 1969. A—Stage 4. B—Stage 6. C—Stage 8. D—Stage 9. E—Stage 10. F—Yolk-sac larva just hatched. (For further explanation see text pages 30 to 35.)

Eggs were examined every 30 minutes during the early cleavages, and thereafter observations were made at longer intervals. Eggs removed from the mixture for observation were preserved. The water temperature fluctuated between 17.2° and 22.2° C during rearing, but little could be done at sea to reduce this variation. Water was frequently renewed with a suction pipette, which reduced the chances of eggs being damaged during the water change. Nevertheless, many eggs died, particularly at the higher temperatures, and these sank to the bottom of the container and turned opaque.

The development time of the various stages as determined from this experiment is outlined in Table 3. The duration of development was 45 to 49 hours at a mean temperature of 19.6° C.

TABLE 3: Development time of the various embryonic stages recorded during artificial rearing

Date Jan	Time	Cumulative time hr	min	Temp. (°C)	Remarks	Stage
25	2315	0	00	19.8	Unfertilised	1
	2330	0	00	19.9	Addition of sperm	1
	2400	0	30	20.0	Protoplasm at animal pole	1
26	0030	1	00	19.9	1st cleavage on 2 eggs	2
	0100	1	30	19.9	1st and 2nd cleavages	2
	0133	2	03	19.8	4th and 5th cleavages	2
	0200	2	30	19.7	Further cleavages*	2
	0230	3	00	19.8	Cell multiplication	3
	0845	9	15	22.1†	Germ ring covers ⅓ yolk	4
	1145	12	15	18.0	¾ yolk covered	5
	1445	15	15	21.3†	⅘ yolk covered	5
	1745	18	15	18.9	Blastopore closed	6
	2045	21	15	19.5	Somites visible	7
	2345	24	15	20.3†	Tail swollen	7
27	0245	27	15	19.2	Tail to oil globule	7 and 8
	0800	33	00	20.9†	Tail separating	8
	1100	36	00	17.6	Tail longer; melanophores	9
	1300	39	00	19.1	Tail bending to side	10
	1600	42	00	21.0†	Tail level with trunk	11
	1900	45	00	17.8	Tail overlaps head	12
	2315	49	15	18.4	Most eggs hatched	

* Counting of cells impossible owing to movement of ship.
† Water changed.

A second rearing experiment was made in January 1969, when pilchard eggs at the blastodermal cap stage were collected from the plankton and their development was timed at a lower and more constant temperature than that of the earlier experiment. The plankton sample was collected from water at 18.8° C in Golden Bay. Eighty-three pilchard eggs, mostly at late stage 3, were removed to an incubator, which maintained the temperature at between 15.0° and 18.0° C. For the purposes of this experiment the eggs were given an age of 6 hours at collection time, based on the age of stage 3 eggs in the earlier experiment. At a mean temperature of 16.5° C, the eggs took 56 to 58 hours to hatch (Table 4).

TABLE 4: Development rate of pilchard eggs collected from the plankton

Date Jan	Time	Cumulative time hr	min	Temp. (°C)	Stage
29	0530	6	00	18.8	3 (late)
	1130	13	00	15.9	4
	1300	14	30	15.2	5
	1430	16	00	15.8	6
	2100	22	30	16.3	7
30	0345	29	15	15.4	8
	1825	44	20	17.8	9
	2235	48	30	16.6	10
31	0205	52	00	16.0	11
	0615	56	10	17.3	12

All eggs hatched by 0830 hr. Mean temperature 16.5°C.

These results on the duration of development of *Sardinops neopilchardus* eggs compare well with data for other *Sardinops* species. Eggs of the Californian sardine have been shown to take 53 hours to hatch at 16.8° C (Ahlstrom 1950), and a peak hatching period between 54 and 56 hours was recorded by Miller (1952), who also kept eggs at 16.8° C. Nakai (1962) incubated eggs of the Japanese sardine at several different temperatures and found that hatching occurred 31 hours after fertilisation at 20.3° C, 52 hours after at 17.5° C, and 75 hours after at 15.2° C.

DEVELOPMENT OF LARVAE

Systematic surveys of larvae are often useful for assisting in the measurement of abundance and availability of fish stocks (Ahlstrom 1965, Cushing 1968), and if a fishery for New Zealand pilchards develops in the future, such surveys could be of great importance to the management of the industry. Thus it is essential that pilchard larvae should be readily recognised at all stages of growth and easily distinguished from other similar clupeoid larvae, of which there are two kinds in New Zealand waters.

Larvae of *Sardinops neopilchardus* have been described only once before from New Zealand waters: Regan (1916, p. 136) reported three larvae 12 to 18 mm long, from Spirits Bay, near

North Cape, in 1911. In Australian waters pilchard larvae have been described from New South Wales by Dakin and Colefax (1934) and from the Queensland and South Australian coasts by Blackburn (1941). Dakin and Colefax described a series of specimens 2.5 to 28 mm long, but failed to notice the pigment pattern in young larvae, stating that pigment first appears in the eyes of larvae about 8 mm long. Blackburn noted that pigment spots were in fact present along the ventral margin of larvae with the yolk sac still attached. In the New Zealand material pigment is present from a late embryonic stage, and considerable migration and development of melanophores take place during early larval growth. Because the early descriptions are incomplete or lack figures, new descriptions and figures of pilchard larvae, based on New Zealand material, are given here.

Three categories of post-embryonic pilchard are recognised: (1) yolk-sac larva, (2) post-larva, and (3) juvenile. The term "yolk-sac larva" is self-explanatory; the "post-larval" period begins once the yolk sac has been completely absorbed. There is a well-defined metamorphosis from post-larva to juvenile in the pilchard, when the young fish ceases to be transparent and develops silver pigment along the flanks. As recommended by Hubbs (1943), the term "larva" is used to include all developmental stages between hatching and metamorphosis.

Yolk-sac Larva

The newly hatched larva (Fig. 22A) is between 2.2 and 2.6 mm long and floats at the surface in an inverted position with the yolk uppermost. It swims downward in irregular short bursts, but returns belly-up to the surface when not actively flexing the tail.

The yolk-sac larva is typically clupeoid in that it is slender, with coarsely granular yolk, a posteriorly located anus, and sparse pigmentation. The single oil globule, lying at the posterior end of the yolk sac, is the main feature distinguishing the very young pilchard larva from those of the two other New Zealand clupeoids, *Sprattus antipodum* and *Engraulis australis*, neither of which has an oil globule.

At hatching the pilchard larva has not completed its embryological development and lacks mouth, gills, and open intestinal tract; the yolk continues to provide nutrition for growth. The eyes of the yolk-sac larva are large and unpigmented, and the large auditory capsules are prominent, as are the notochord and lateral muscle bands. The dorsal fin fold is erect and smooth in outline, with a slight dip above the tail, and the ventral fin fold is constricted at the anus. The pectoral fin buds are not yet visible, but there are traces of caudal fin lepidotrichia near the tail tip. There are two rows of dendritic melanophores on the dorsal surface, one either side of the fin fold, and a series of widely spaced, small pigment spots on top of the head. These melanophores migrate down the sides of the body to the ventral margin of the larva within about 24 hours of hatching (Fig. 22A and B). The neuromast organs are now prominent as lateral rows of eight to 10 along each side of the body (Fig. 21). These sensory organs have not been reported in *Sardinops* before, though they have been described in the European pilchard (*Sardina pilchardus* (Walbaum)) by Lebour (1921) and Blaxter (1969).

When the yolk-sac larva is between 3.0 and 3.5 mm in body length, the head region straightens and the pectoral fin buds appear. The melanophores are now placed ventrally, one row along

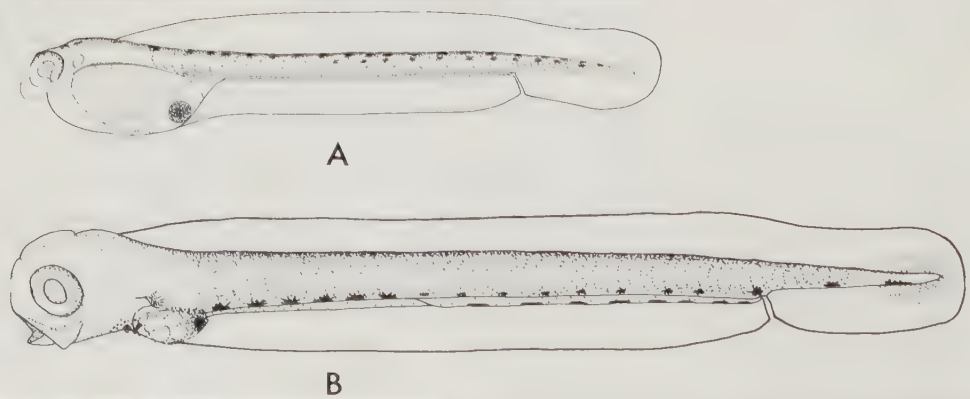


Fig. 22: Pilchard larvae. A—Yolk-sac larva 3.0 mm in body length. B—Yolk-sac larva 4.5 mm in body length. Note: Figures 22 to 26 and 31 are made from preserved material, and because of the opacity of the muscles certain features such as the notochord do not show up as in living specimens.

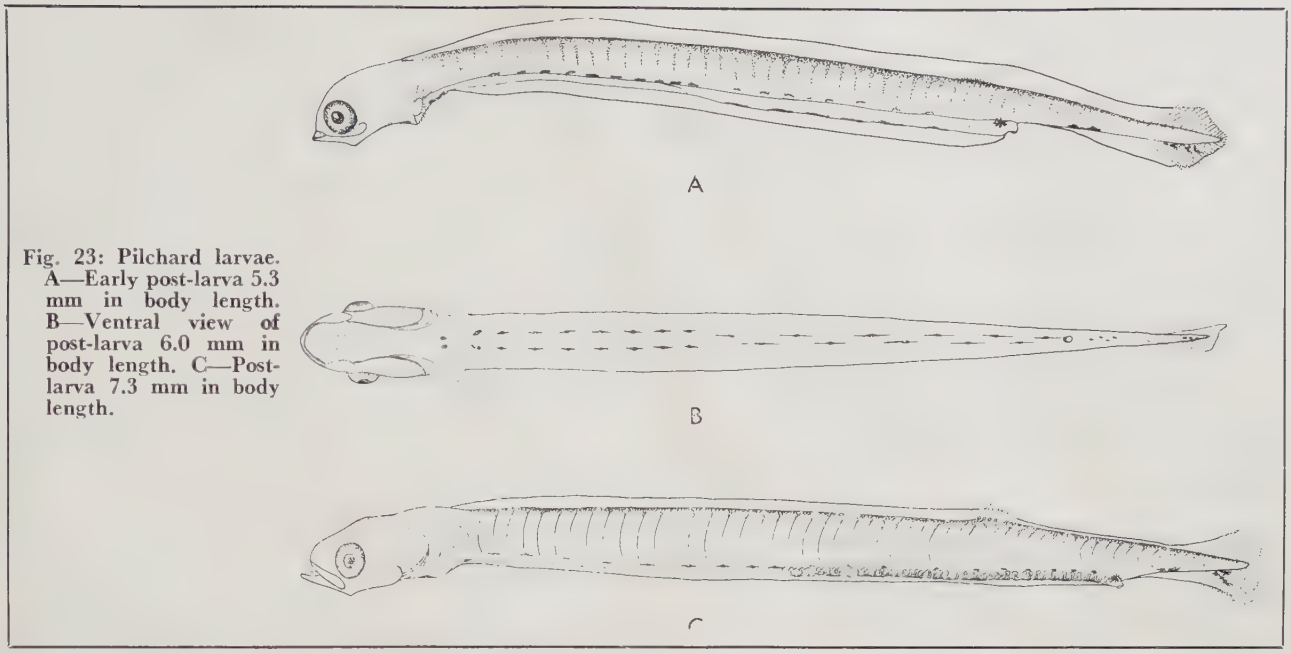


Fig. 23: Pilchard larvae. A—Early post-larva 5.3 mm in body length. B—Ventral view of post-larva 6.0 mm in body length. C—Post-larva 7.3 mm in body length.

each side just above the gut and a single row on the ventral edge posterior to the anus. The oil globule is somewhat more irregular in shape, and the yolk sac is smaller than in the newly hatched larva.

At about 4.5 mm in body length (Fig. 22B), some 48 hours after hatching, the yolk sac is much further reduced and the oil globule is minute. The pectoral fins and the caudal lepidotrichia are more noticeable, and the fin folds are not quite as deep in relation to the body depth. The cerebral hemispheres are prominent at this stage, the mouth is beginning to develop in a ventro-subterminal position, and some pigment is present in the eye. There are one or two pigment spots in the gular region on the ventral midline, and two larger spots immediately behind the bases of the pectoral fins. On either side of the abdomen anterior to the pylorus are six or seven superficial pigment spots, and following the same horizontal line posteriorly above the intestine are five to eight deeper-set spots. A prominent pigment spot is situated just above the anus. There is a double row of 11 to 15 adjacent, longitudinally elongated pigment spots along the underside of the intestine, three to five spots under the tail, and a similar number associated with the caudal lepidotrichia.

Post-larva

When the larva is about 3 days old and has attained a length of 5.0 to 5.5 mm, the yolk sac is completely absorbed (Fig. 23A). The slenderness of specimens at this stage is due to elongation of the body and a slight decrease in fin fold depth relative to the body depth, which appears to be much narrower. The pigment pattern is similar to that of the last stage except that the eye is fully pigmented and the melanophores along the ventral edge of the intestine are now alternately placed and are very elongated (Fig. 23B). The intestine is noticeably convoluted, a typical clupeoid character. Lepidotrichia are more numerous in the caudal region and are also present in the pectoral fins.

All pilchard larvae reared from eggs on the research vessel died soon after complete absorption of the yolk sac. Although the mouth was well formed in these specimens, and they were very active, none was observed to feed on the *Artemia* nauplii introduced into the rearing jars. However, larvae as small as 6.0 mm long are able to ingest food organisms, because a specimen of that length collected from the plankton contained a small nauplius, and others, 9.0 mm and 12.0 mm long, contained a gastropod veliger and a copepod respectively.

The following series of post-larvae are described from material taken from plankton and dip-net samples. Increase in size and the appearance of fins are the main features associated with the next few stages.

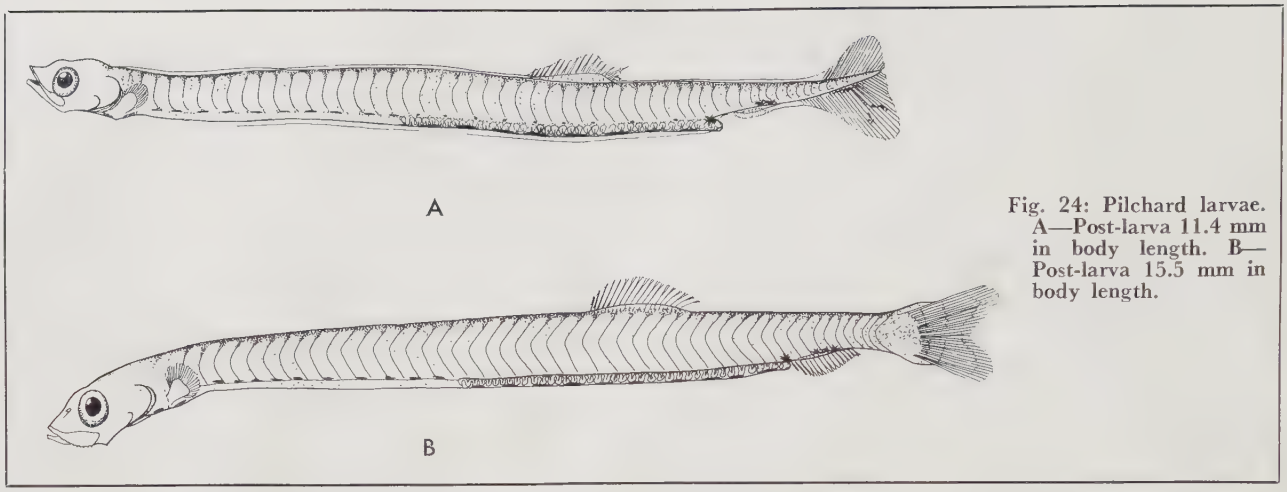


Fig. 24: Pilchard larvae. A—Post-larva 11.4 mm in body length. B—Post-larva 15.5 mm in body length.

At a body length of 7.3 mm (Fig. 23C) the fin folds are much further reduced in height, and the dorsal fin lepidotrichia are beginning to form. The caudal fin is much more advanced, but there is no sign of the pelvic or anal fins. Fine serrations are evident on the lower edge of the premaxillary bones at this stage. The pigment pattern at this length is the same as in the previous stage and remains essentially so through to post-larvae of about 22 to 25 mm long.

The anal fin appears when the larva is about 11.0 to 11.5 mm (Fig. 24A), and the ventral lobe of the caudal fin becomes longer than the dorsal lobe; in many larvae pigment spots are scattered through the lobes. The tip of the notochord begins to turn up when the larva is about this size, and the dorsal and ventral fin folds have almost disappeared.

Post-larvae 15 to 16 mm long (Fig. 24B) have a complete set of dorsal fin rays (17 or 18) and show the beginnings of a caudal fork. The notochord is upturned and the hypurals are prominent. There is pigment in both lobes of the caudal fin, usually regularly placed in several vertical bands which follow the contour of the tail margin. The fin fold membrane is no longer present.

The pelvic fins appear when larvae are between 18 and 20 mm long (Fig. 25A) and are situated alongside the pyloric region of the gut. The anal fin is now complete, with 16 or 17 rays. At 25 mm (Fig. 25B) all the fins are well developed, and a few pigment spots may be present along the lateral midline above the anal fin and also on the head, particularly above and immediately below the eyes and on the pre-opercula.

Some specimens at this length show the first indication of scales, which develop as thin round platelets on the caudal peduncle and extend anteriorly in several horizontal rows to form a long V, with the smallest platelets at the apex. At first

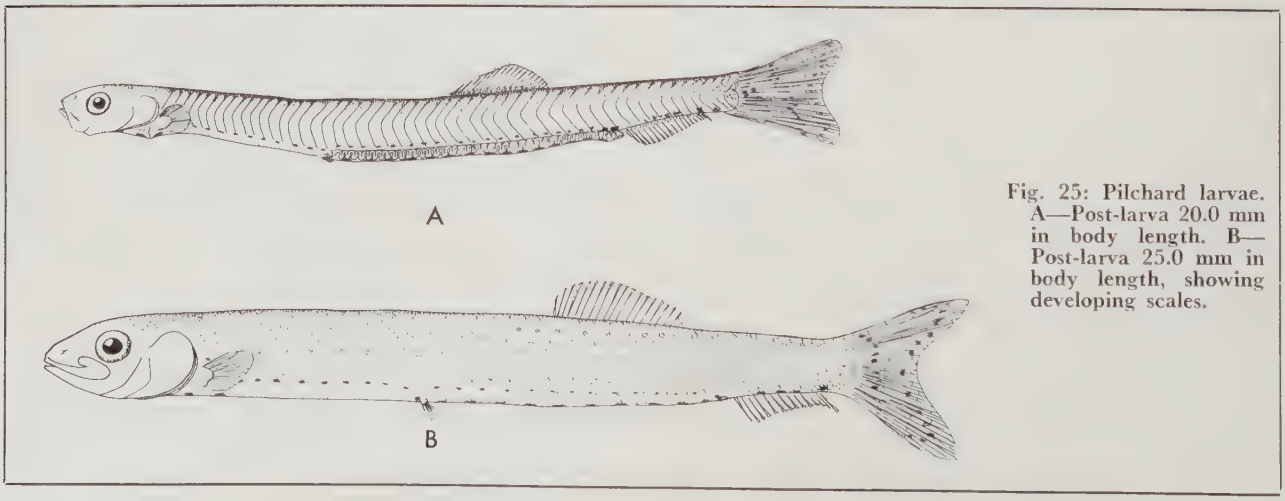


Fig. 25: Pilchard larvae. A—Post-larva 20.0 mm in body length. B—Post-larva 25.0 mm in body length, showing developing scales.

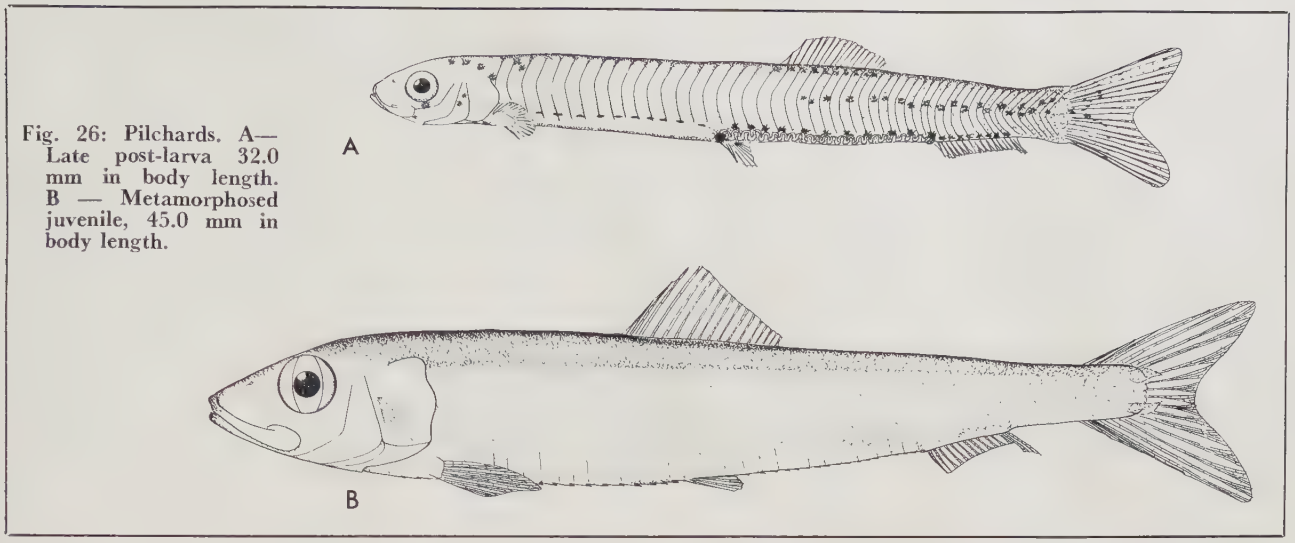


Fig. 26: Pilchards. A— Late post-larva 32.0 mm in body length. B — Metamorphosed juvenile, 45.0 mm in body length.

each scale platelet is isolated from its neighbour, but as they develop anteriorly the posterior ones enlarge and begin to overlap (Fig. 25B). When the body length reaches 35 to 40 mm the whole body is covered by small overlapping scales. According to Scofield (1934), the Californian sardine has developed recognisable *Sardinops*-type scales by a standard length of 34 mm, but Davies (1954), on the other hand, found no scales on juvenile South African pilchards at 42 mm total length (*c.* 36 to 37 mm standard length).

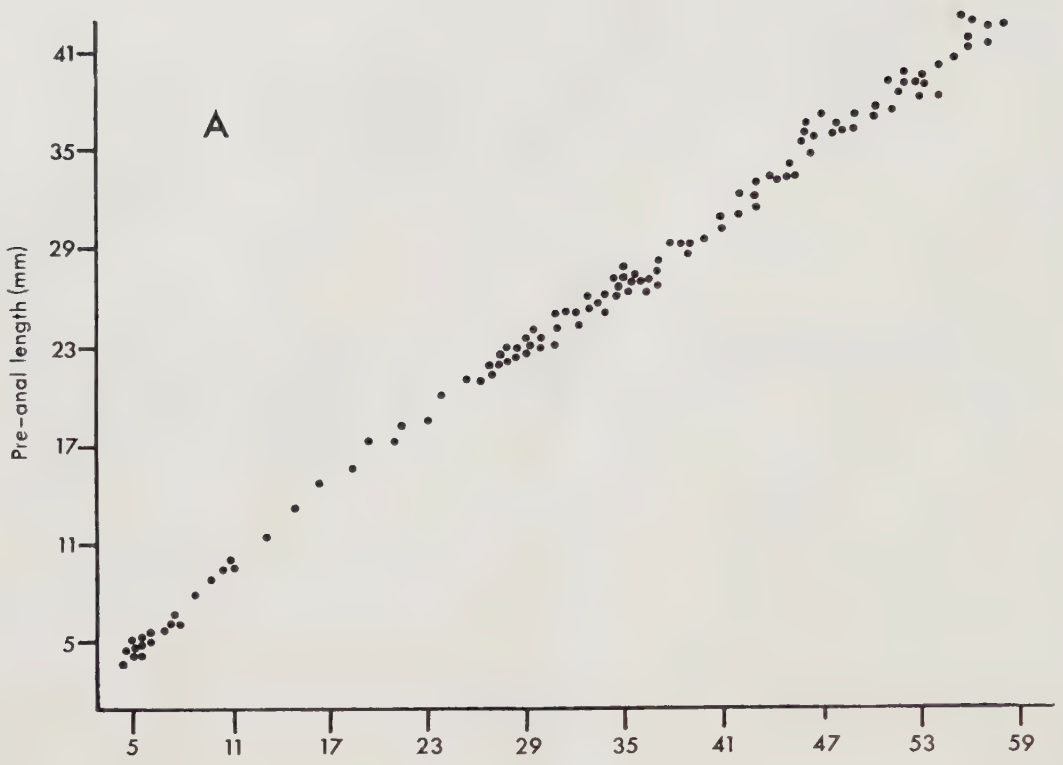
Pigmentation increases strikingly between 25 and 35 mm; post-larvae of this size usually have a mid-lateral band of multiple pigment spots which often extend anteriorly to about level with the pelvic fins. There are also one or two rows of melanophores along the dorsum from the caudal peduncle to immediately anterior to the dorsal fin (Fig. 26A).

METAMORPHOSIS TO THE JUVENILE

Metamorphosis from post-larva to juvenile takes place in the pilchard at body lengths between 35 and 40 mm and involves changes in body form and pigmentation. The body deepens, becomes laterally compressed, and is less elongate. The relationship between various morphometric measurements and body length for 140 post-larval and juvenile pilchards is illustrated in Figs. 27 to 30. The essentially linear relationships shown indicate a proportional pattern of growth. The relationship between greatest depth of body and length is, however, curvilinear (Fig. 27B), and the steepness of the curve between 25 and 40 mm body length indicates the change in these proportions during metamorphosis.

During late post-larval growth and metamorphosis of the pilchard there is considerable migration of fins and the anus along the long axis of the body. The pelvic fins migrate posteriorly over a distance of about five myotomes (seventeenth to twenty-second), and the dorsal fin and anus move anteriorly over 12 (twenty-seventh to fifteenth) and four (thirty-ninth to thirty-fifth) myotomes respectively (Fig. 30). When the pelvic fins first appear they are thus much closer to the head than is the dorsal fin, and as the body length increases, the fins move toward each other. The dorsal fin covers the greatest distance, and at about 32-35 mm in body length the first dorsal ray is vertically above the origin of the pelvic fins; movement continues until the pelvic fins lie vertically below about half way along the dorsal fin, in which relative positions the fins then remain. This anterior movement of the dorsal fin during metamorphosis is indicated by the inflection in the scatter of points in Fig. 28A. At the same time the anus is migrating forward; this movement is, however, of smaller magnitude than that of the dorsal fin, and the distance between the anus and dorsal fin actually increases.

The graphs showing the positions of dorsal fin and anus in respect to myotomes (Fig. 30) indicate that a reversal of movement, involving a distance of one or two myotomes, takes place during late metamorphosis. A similar phenomenon has been noticed during metamorphosis of the British herring, *Clupea harengus* L., by Ford (1930).



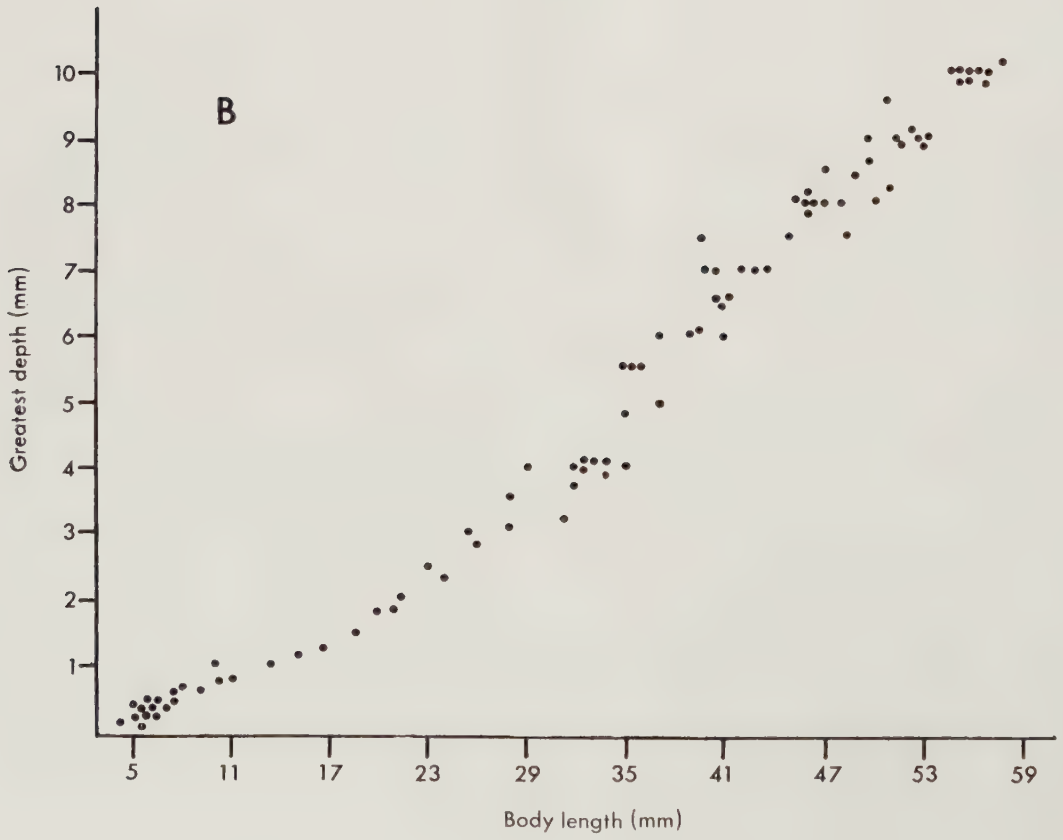


Fig. 27: A—Relationship between pre-anal length (distance from tip of snout to origin of anal fin) and body length. B—Relationship between greatest depth of body and body length.

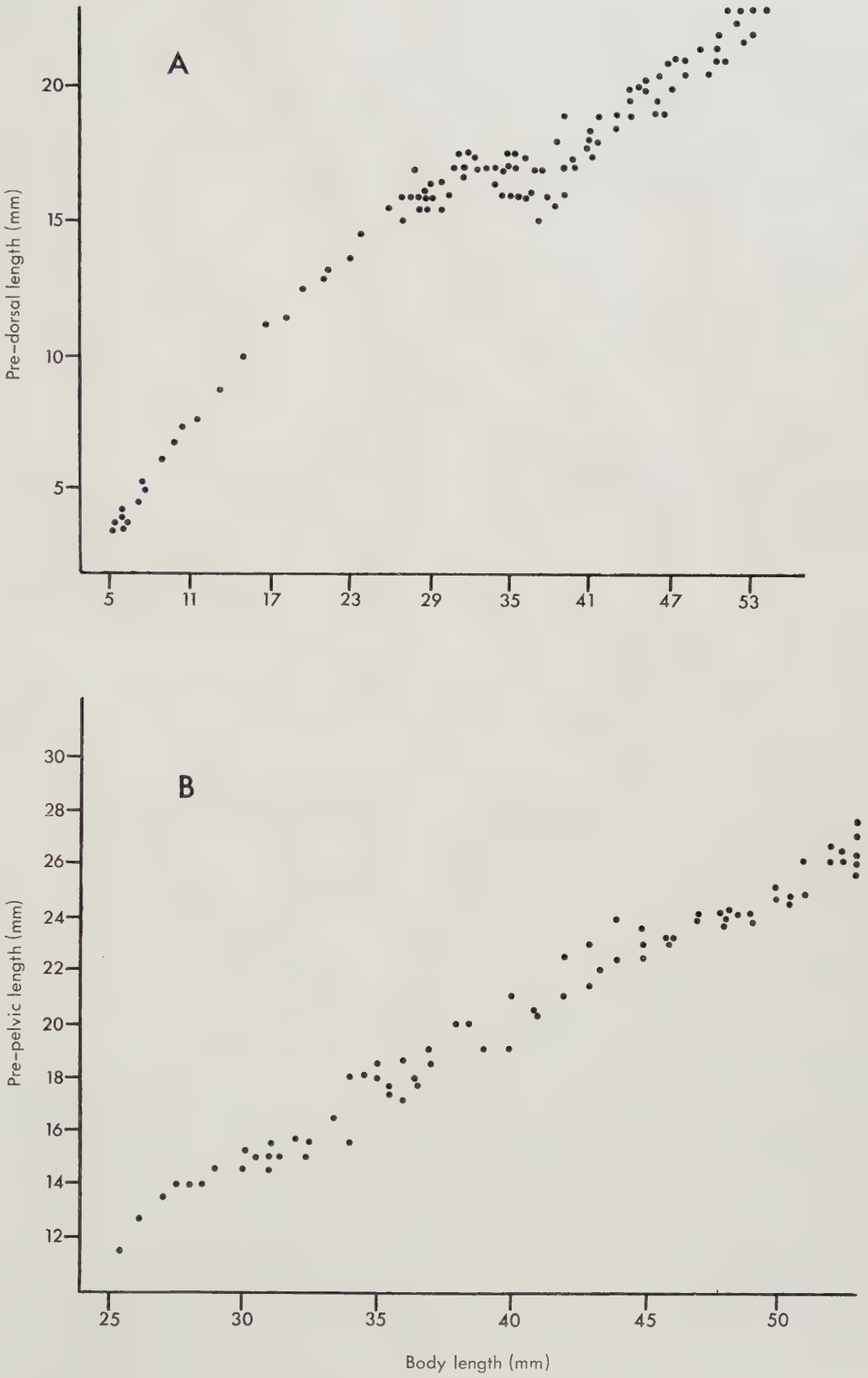


Fig. 28: A—Relationship between pre-dorsal length and body length. B — Relationship between pre-pelvic length and body length.

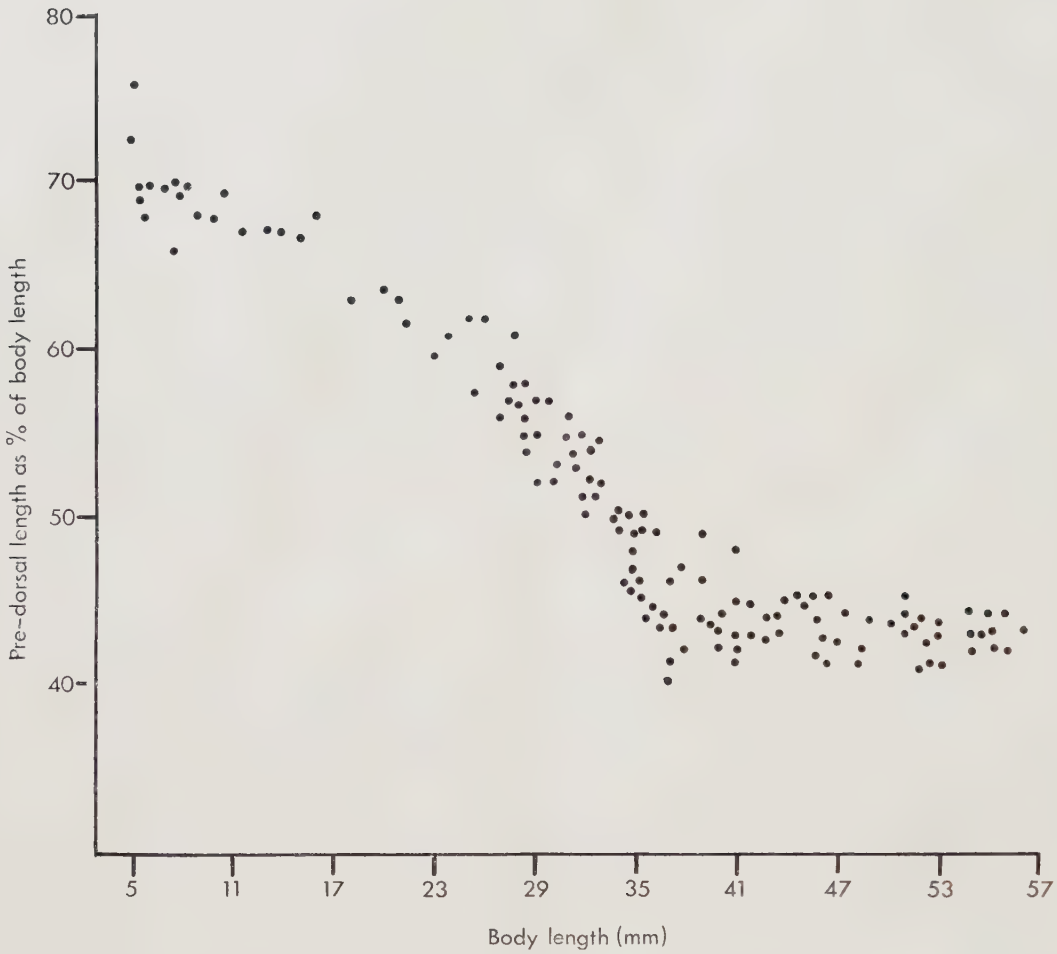


Fig. 29: Relationship between pre-dorsal length (as a percentage of body length) and body length.

Alteration in the positions of fins and the anus during the growth of young clupeoid fishes has been well documented for European species of pilchard, sprat, and herring by Fage (1920), Lebour (1921), Schnakenbeck (1929), and Ford (1930). The last author convincingly ascribes this relative movement of fins and anus to three distinct systems of differential growth in the body of the larval fish—along the dorsal surface, along the vertebral column, and along the ventral surface.

Within the genus *Sardinops* the phenomenon of fin migration has been noted in larvae of the Californian sardine by Scofield (1934), the Australian pilchard by Dakin and Colefax (1934) and Blackburn (1941), and the South African pilchard by Davies (1954).

Between 35 and 40 mm in body length the metamorphosing larvae of *Sardinops neopilchardus* begin to acquire the basic adult colour pattern—dark dorsal surfaces and light lateral and ventral surfaces. At first a row of melanophores is present along the back on each side of the dorsal midline, and there is a wide band of spots running horizontally between the dorsal corners of the opercula and the end of the caudal peduncle. This lateral band lies at about one-fifth of the body depth from the dorsal edge and is connected to the dorsal row by parallel oblique rows of melanophores which lie above each myocomma between the myomeres. Dark pigment spots of various sizes also appear on the very anterior tips of the upper and lower jaws, along the ventral edge below the jaws, and on top of the head, particularly over the cerebral hemispheres. Pigmentation of the dorsal and caudal fins increases during metamorphosis, and pigment spots also appear at the bases of the dorsal and anal fins. There is one pigment spot on each side of the origin of the pelvic fins.

Silver pigment first develops on the sides of the head and the opercula; it spreads along the lower four-fifths of the body and tapers away toward the posterior extremity of the caudal peduncle. As the young fish increases in size the silver pigment eventually covers the ventral and lateral surfaces

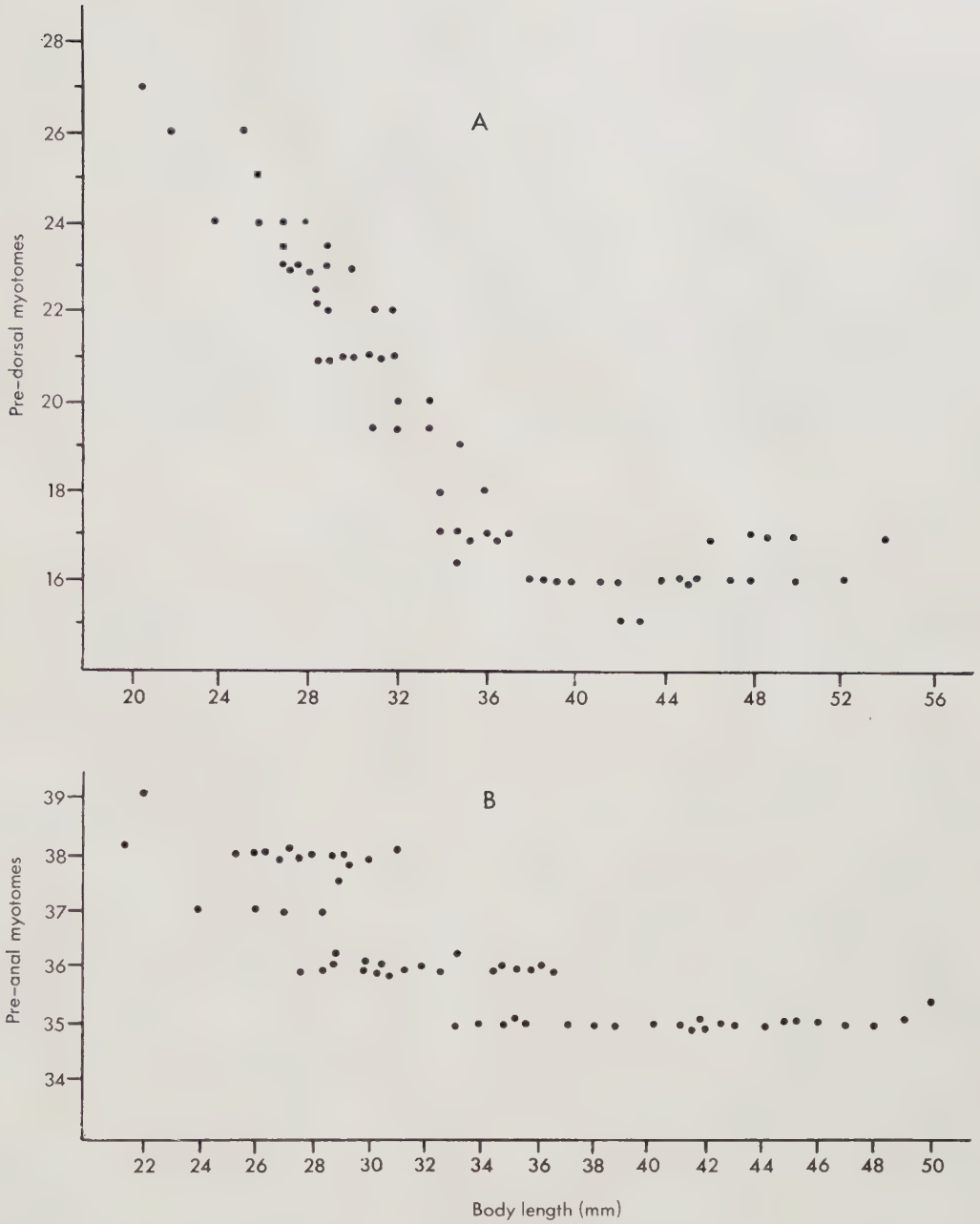


Fig. 30: A — The position of the origin of the dorsal fin in relation to the number of myotomes preceding it, at various body lengths. B—The position of the origin of the anal fin in relation to the number of myotomes preceding it.

of the head and trunk, and the dark pigment spreads over the dorsal area and develops blue tonings.

When the juvenile pilchard has grown to 50 to 60 mm in body length it has assumed most of the features characteristic of the adult fish. Two adult characters in particular now serve to identify the species positively—a fan-like arrangement of striations on the opercular bones and a single row of large dark spots on each side of the body along the line of colour change from silver to dark blue. Apart from its slightly more compressed body width and shorter length, the juvenile pilchard is otherwise identical to the adult.

DISTINGUISHING FEATURES OF LARVAE AND JUVENILES

Larvae of the pilchard are very similar to those of the New Zealand anchovy (*Engraulis australis*) and sprat (*Sprattus antipodum*) and can be distinguished from them only by consideration of several detailed features. All three species have typical larval clupeoid characters — a slender,

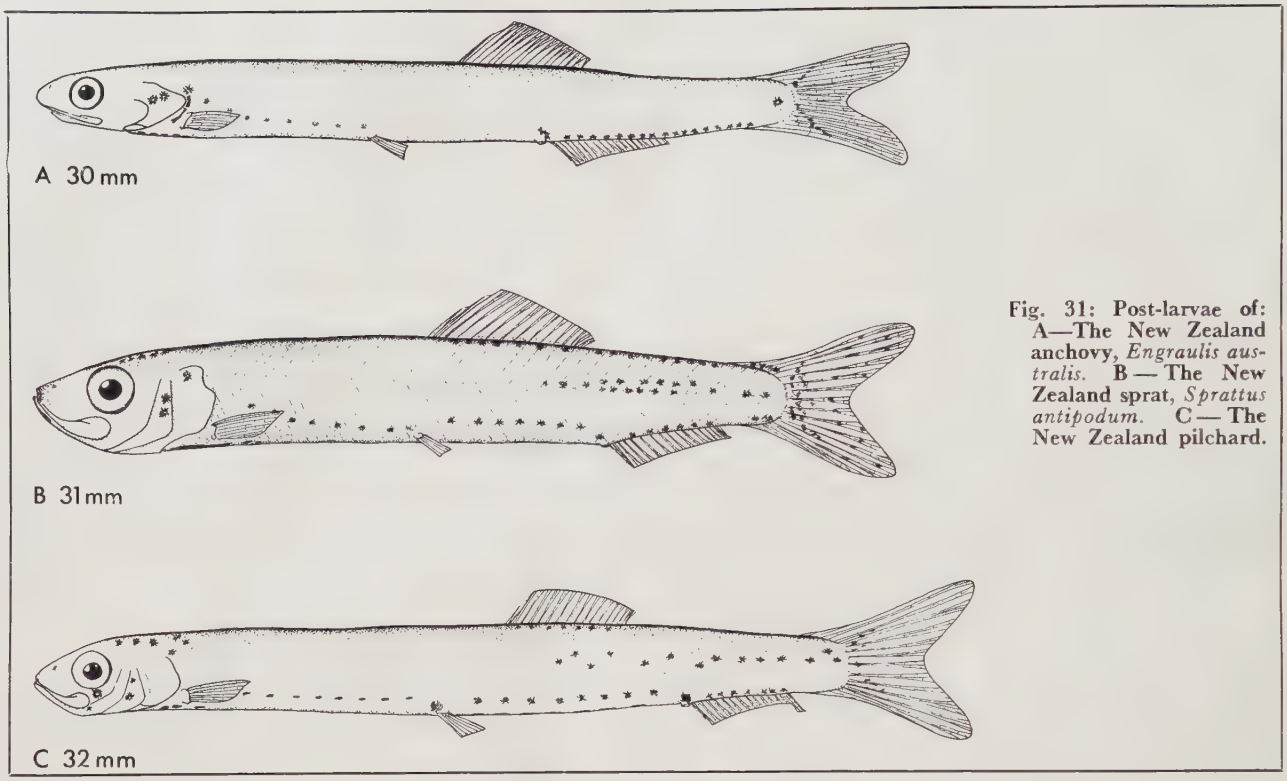


Fig. 31: Post-larvae of: A—The New Zealand anchovy, *Engraulis australis*. B — The New Zealand sprat, *Sprattus antipodum*. C — The New Zealand pilchard.

sparsely pigmented body, with a tightly convoluted intestine and posteriorly placed anus.

The anchovy larva can be separated from the larvae of the other two species mainly by differences in the relative positions of fins. For example, the dorsal and anal fins develop much earlier in the anchovy than in the pilchard or sprat. The fins are present at a body length of 5.44 mm, whereas in pilchards of this length even the dorsal fin is not yet visible. In the anchovy the anus initially lies vertically beneath the posterior ray of the dorsal fin, and as the larva grows, the anus and anal fin migrate forward slightly, so that eventually the two fins overlap and the anus lies beneath the midpoint of the dorsal fin (Fig. 31A). In the pilchard and sprat, however, the dorsal and anal fins are always separated by a distance equivalent to 10 to 19 myotomes. Furthermore, at about 20 mm in body length the head of the anchovy larva is characteristically rounded at the snout, and the jaw is underslung, with the maxillary extending beyond the posterior margin of the eye (Fig. 31A). The snout is not rounded and the mouth is terminal in the two other species.

Differences between the larvae of pilchards and sprats are not so clear-cut, and the relative positions of fins are not good separating characters. A detailed study of fin movements in the sprat has shown that the pelvic fins migrate backward over two myotomes (seventeenth to nineteenth), the dorsal fin migrates forward over seven myotomes (twenty-fifth to eighteenth), and the anus migrates forward over four myotomes (thirty-fifth to thirty-first). The movements are similar to those which take place in the pilchard, except that the magnitude of movement of the pelvic and dorsal fins is smaller in the sprat, and the anus lies somewhat closer to the dorsal fin.

Differences in pigmentation are more useful for separating the two species: in the sprat there is an elongate melanophore in the gular region, which extends backward to immediately below the pectoral girdle, and there are two smaller melanophores behind the pectoral girdle. In the pilchard, on the other hand, there are one or two small melanophores ahead of the girdle and two larger ones behind it. There is a single row of elongate melanophores along the ventral edge of the intestine in the sprat, whereas the pilchard has a double row of either adjacent or alternate melanophores in this region.

In pilchard larvae between 25 and 35 mm in body length a melanophore is usually present on the side of the head just beneath the eyes; this pig-

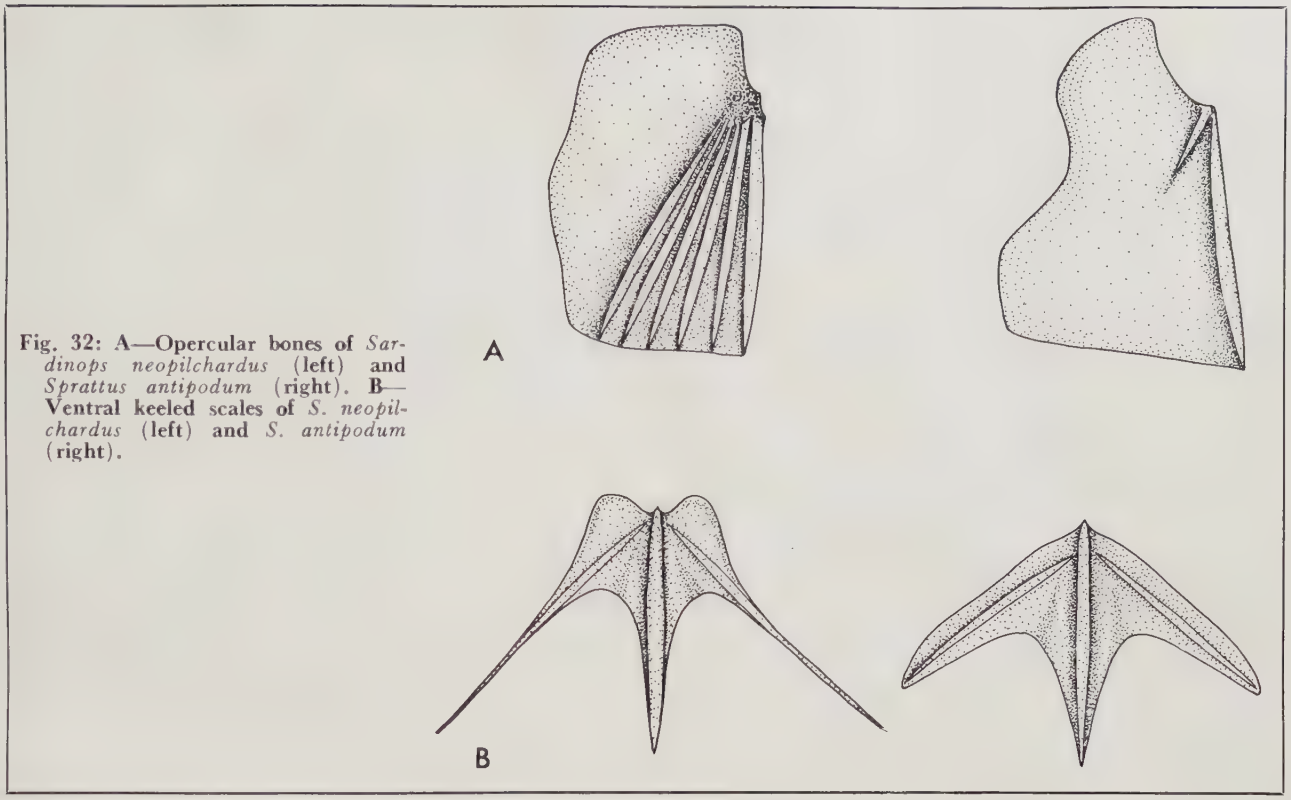


Fig. 32: A—Opercular bones of *Sardinops neopilchardus* (left) and *Sprattus antipodum* (right). B—Ventral keeled scales of *S. neopilchardus* (left) and *S. antipodum* (right).

ment spot is not present in the sprat. In addition the sprat does not have a melanophore at the origin of the pelvic fins as does the pilchard. Lateral pigmentation is less determinate, but the sprat does have a row of large superficial melanophores at about the level of the roof of the abdomen, which are not present in the pilchard.

Other features which can be used to distinguish late post-larvae of these species are the presence of an elongate last ray in the anal fin, and two large scales at the base of the tail in the pilchard, and differences in the shape and sculpture of the opercular bones (Fig. 32A) and ventral keeled scales (Fig. 32B). The range in numbers of vertebrae for each of the three New Zealand clupeoid species is: pilchard 49 to 52, sprat 44 to 46, anchovy 43 to 47; other meristic counts overlap.

AGE AND GROWTH RELATIONSHIPS

The age and growth of *Sardinops neopilchardus* were investigated by use of two standard methods: analysis of seasonal length-frequency distributions and examination of scales for annual rings or other periodic structures.

AGE AND GROWTH OF JUVENILE PILCHARDS

Juvenile pilchards less than 1 year old showed no rings on scales that could be regarded as the first in a periodic series. The age of these young fish was therefore assumed by relating it to the spawning season at the beginning of the particular year in which they were collected. By following the progression of length-frequency modes through the seasons, it was possible to derive an approximate rate of growth for juvenile pilchards in their first year of life. Such information provided a starting point for associating age with periodic rings which appear on scales of fish older than 1 year.

Most fish were collected in a fine-meshed hoop net near a light at night—a method which caught almost every fish within the compass of the net irrespective of size. Similarly, other samples taken from predator stomachs and fine-meshed beach seines were assumed to give a reasonably reliable indication of the size composition of the juvenile pilchard population for the years sampled. The real problem raised by these sampling methods was, however, the small numbers of fish which they usually provided. During summer schools of small pilchards were often seen at the surface, but could not be caught with the equipment available.

It was assumed that the young fish collected were representative of schools which originated in Tasman Bay and the Marlborough Sounds, but no allowance could be made for the possibility of different broods of juveniles in the catches. With the spawning season extending over 3 to 4 months, one might expect to find multimodal, or at least skewed, length-frequency distributions in samples of juvenile pilchards, the separate modes representing different spawnings. Several polygons in Fig. 33 do in fact show such asymmetry. The shape of length-frequency distributions will therefore fluctuate according to the heterogeneity of the sample and changes in growth rate of the pilchards.

The sample for April 1966 shown in Fig. 33 contained post-larval and metamorphosing pilchards ranging in body length from about 20 to 39 mm, with a mode at 25 to 29 mm. Because of its largely larval nature, this group was regarded as having originated during the previous spawning season. If the subsequent samples represented fish spawned at about the same time as the April ones, growth can be traced by the monthly progression of modes through to September. The data for 1966 show growth increments for these samples of 7 mm in 38 days (April-May), 5 mm in 40 days (May-July), and 10 mm in 71 days (July-September). Although the samples were small, they showed growth increments of a similar order, with an average of 4 mm per month. This seems a feasible growth rate, considering that Davies (1957) showed that in the warmer waters of South Africa pilchards may increase in length at a rate of 8 mm per month.

Extrapolation of this tentative growth rate of 4 mm per month over the remaining 3 months of the year gives a body length of 55 to 60 mm by January. Although no fish of this size range were caught in 1966, samples were available for 1964 and 1965 from nearby Paraparaumu Beach (Fig. 1) which had modal lengths of 50 to 54 mm and 55 to 59 mm respectively. Although these samples represented a different year class, which may have had a different growth rate, it still seems probable that pilchards could attain a length of 55 to 60 mm 10 to 12 months after spawning. This agrees with the modal length of 55 mm suggested for 1-year-old Australian pilchards by Blackburn (1949).

Data for 1967 were even more scant than those of the previous year. Only two large samples of juvenile pilchards were collected—one in mid-July and the other in early August. The main modal length groups fall within the 40 to 44 mm range, and the size of class interval used in grouping the length distributions has obscured a 2-mm difference in the position of the modes. Although this possible growth increment is about half the average monthly figure calculated for 1966, it represents the only two consecutive winter samples and may illustrate a slow winter growth rate.

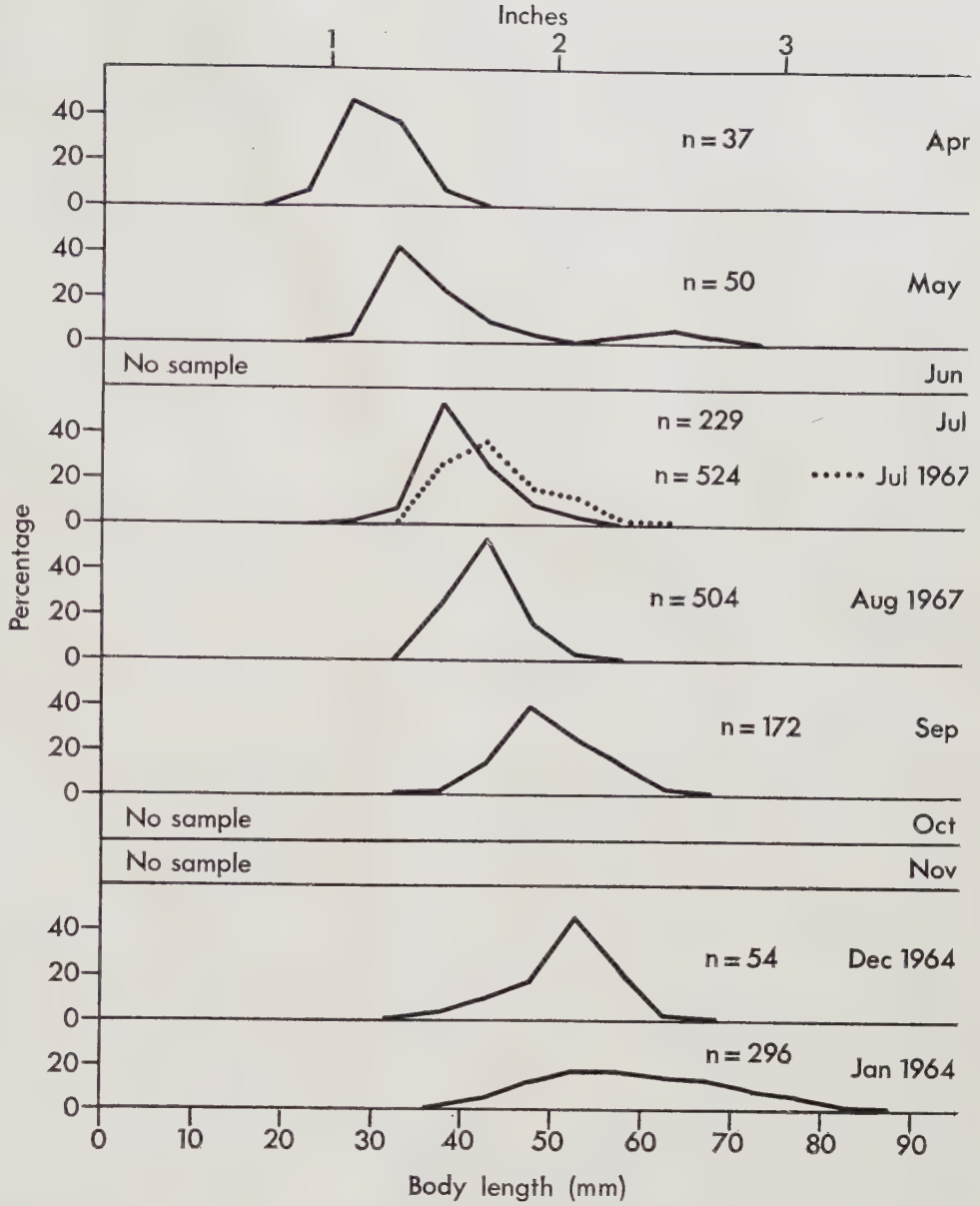


Fig. 33: Length-frequency polygons for catches of juvenile pilchards taken in the Marlborough Sounds - Tasman Bay area. (December and January samples are from Paraparaumu Beach.) Months fall in 1966 unless specified.

AGE AND GROWTH OF ADULT PILCHARDS

Unlike the length-frequency distributions for larval and juvenile samples, those for samples of adult fish gave no indication of seasonal growth. There was no definite progression of modal sizes through the seasons, though one or two dominant modes usually occurred in each sample. In the drift net samples these modes probably reflected the selective action of the different meshes. The lampara and trawl nets should have been less selective than the drift nets, but the samples obtained from the former were too few and too widely separated in time to give an indication of seasonal growth.

A comparison between the total catches by drift nets and lampara and trawl nets (Fig. 34) shows that the drift nets took two main length groups of pilchards, with modes at 120 to 124 mm and 160 to 164 mm, whereas catches in the other nets consisted of three main length groups with modes at 95 to 99 mm, 120 to 124 mm, and 155 to 160 mm. The size of mesh used in drift nets affects the length and age composition of catches by selecting fish of certain cross-sectional dimensions irrespective of length or age. Such selection can lead to inaccurate determinations of average lengths for various age groups. If a series of different mesh sizes are fished together, the effects of selection can be balanced to some extent (see Pope 1966). Ex-

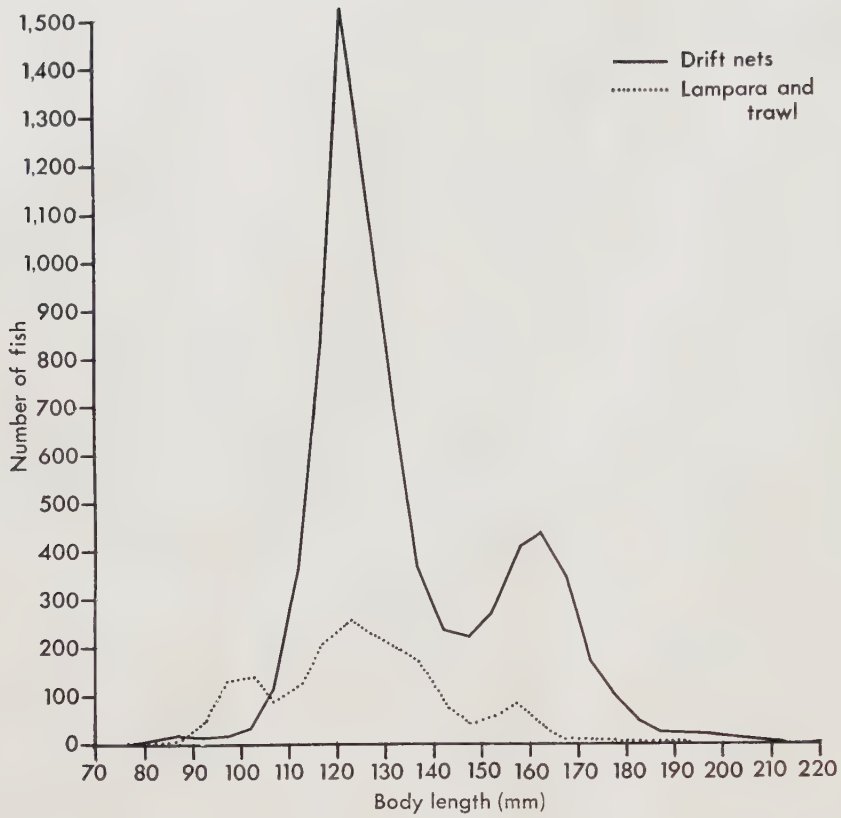


Fig. 34: Length-frequency polygons for all pilchard measurements available.

periments along these lines on the Irish herring (*Clupea harengus*) indicated that when several nets are used together, selection is much less in practice than it seems to be in theory (Department of Agriculture and Technical Instruction for Ireland 1905).

In the present investigation the four drift nets of different mesh sizes caught a wider range of length groups of pilchards than any other method of fishing tried, and the length distributions of fish taken by the nets overlapped considerably (Table 5). The main effects of the drift nets were the undersampling of small length groups and oversampling of large length groups (large fish were caught in small meshes by becoming entangled by small facial bones such as the maxillary and preopercular). The dominant length mode (120 to 124 mm) appeared in 75 percent of the drift net samples, including those taken in consecutive months of both years, and was therefore regarded as a selected length group. However, because the drift net samples provided the only consecutive samples of pilchards of a wide range of lengths, they were used, albeit cautiously, for age-growth studies by scale analysis. It was considered at first that the scales from such samples would at least provide some basic data on the seasons and circumstances of ring formation. When a reasonably close agreement between the average intermediate lengths calculated from the scales for the various

TABLE 5: Size composition of 5 pilchard samples from different mesh sizes. The catches in all nets except the ¾-in. mesh were taken within a few minutes of each other in one bay

Length group (mm)	¾-in. mesh	1-in. mesh	1¼-in. mesh	1½-in. mesh	Lampara
80-84	1				1
85-89	3				3
90-94	16				6
95-99	7				9
100-104	10				19
105-109	5	2		1	39
110-114	4	12	3	2	54
115-119		32	6	3	36
120-124		40	10		24
125-129		39	7	4	22
130-134		18	3	13	17
135-139		3	2	19	3
140-144		5	7	19	
145-149		2	4	13	
150-154		2	3	14	
155-159		6	3	20	
160-164		2	2	11	
165-169		4		1	
170-174		2	1	1	
175-179		1		1	
180-184		1			
Total	46	171	51	122	233

age groups became evident, it was decided that the growth data from drift net samples could be used to illustrate possible growth tendencies in the pilchard.

AGE AND GROWTH FROM SCALE STUDIES

The methods of examination and analysis of scale data for age determinations adopted for this study are based largely on those used by Blackburn (1949, 1950) in his study of *Sardinops neopilchardus* in Australian waters. The structure of pilchard scales and the difficulties in determining the age of fish from them have been extensively reviewed by him; the problems included secondary rings, omitted or imperfect rings, double rings, obliteration of early rings by later ones, and the interpretation of the scale edge. These same difficulties applied to New Zealand *Sardinops* scales, which showed a similar succession of rings to the Australian samples.

In the present study scale samples were examined to find what relationship existed between scale growth and fish growth, whether regular periodic rings were formed, and whether use could be made of such information by way of back calculating fish lengths at ring formation to give a measure of the growth of pilchards.

Selection of Scale Samples

To decide on a scale sampling site, five scales were taken from each of seven areas on 14 fish, and the variation in regularity of scale shape, length of the anterior portion of the scales, and the clarity of rings was compared. The seven sampling areas are shown in Fig. 4. Scales from area 4 proved to be the most reliable for clarity and uniformity of shape; they also showed the least variation from the average anterior scale length. Whenever possible up to six scales were sampled from near the centre of this area.

Recognition and Selection of Rings

Three types of rings are present on New Zealand pilchard scales:

(a) **Yearly rings,** which appear as narrow, continuous light bands (in transmitted light) running parallel to the scale margin around the entire sculptured anterior portion of the scale and often around the posterior portion. They are present in the same relative position on most scales of an individual fish.

(b) **Condition rings,** which are also narrow light bands running parallel to the scale margin; they are particularly prominent on the sides of the scales, where they usually coincide with the yearly rings to form a wide "break" in the striae.

(c) **Accessory rings,** of which several may occur on one scale in various degrees of completeness and sharpness. They often precede the first yearly ring and are perhaps caused by irregular environmental upsets to which the fish has been subjected (for example, sudden changes in salinity or temperature).

The methods used to identify yearly rings in this study were:

(a) The determination of the most complete and/or distinctly marked ring, on the assumption that such a ring would be the yearly one. (This was not always so.)

(b) A comparison between uncertain rings and definite examples of the same yearly rings on other scales from the same set.

(c) A comparison of the intermediate lengths in question with the modal value for the particular ring under consideration.

(d) A consideration of the time of year when the fish was caught, and the closeness of the ring to the scale margin, in relation to the season of ring formation.

(e) Selection of a ring according to the most likely annual increment.

With these methods yearly rings were selected for most of the scales examined. Some scales, however, had incomplete rings, had rings missing (particularly the first), or were totally without rings; most of these were discarded. In all, 641 fish provided scales from which some usable measurements were obtained.

Treatment of Material and Data

Scales were examined with a sliding screen projection apparatus similar to that described by Kesteven and Proctor (1941). Anterior scale length (S) and intermediate lengths to scale rings (L_1, L_2, L_3, etc.) were measured along a radius from the centre of the basal line to the anterior apex. The scale images were magnified 30 times, and measurements to the nearest 0.1 mm were read off a similarly enlarged grid on the

screen. The anterior length was recorded for every normal scale in each series and an average value calculated. The most readable scale with dimensions closest to the average was then examined in greater detail: the anterior length and intermediate lengths were recorded, and the sliding screen was moved away from the projector until the image of the anterior scale length was equal to the length of the fish from which it was taken. L_1, L_2, etc., were then recorded as actual fish lengths at the time of ring formation.

Recording intermediate lengths as fish lengths depends on the assumption that a relationship exists between scale length and fish length (see Lea 1910, Chugunova 1959). A directly proportional linear relationship between scale length and fish length would be expressed by the formula $L = B.S$ (L = fish length, B = constant, S = scale length), whereas a relationship in which the growth increments of scale and fish are directly proportional would be expressed as $L = A + B.S$ (A = another constant). Analysis of the L and S measurements from the present material (Table 6) shows that the relationship is of the second kind, and that it may be expressed by the regression equation:

$$L = 23.47 + 30.14S.$$

Because the scale length and fish length are not directly proportional, the intermediate lengths obtained from the enlarged scale image must be corrected by use of the formula:

$$Ln = A + \frac{Ln^1}{L}(L - A),$$

where Ln = the corrected anterior scale length, Ln^1 = the intermediate length obtained by the direct proportion method, L = fish length, and A = a constant derived from the above regression equation. This correction formula is derived from Lee's (1920) formula for direct calculation of intermediate lengths from empirical data. It was used in the form:

$$Ln = Ln^1 + 23.47\left(1 - \frac{Ln^1}{L}\right),$$

to correct all intermediate lengths obtained by direct proportion in the present study. A check, by comparing the corrected lengths with some calculated from empirical data by Lee's (1920) method, showed close agreement.

Season of Ring Formation

To discover the time of year at which the first yearly ring was formed, the percentage of scales with one ring and an L_1 measurement within 10 mm (on the enlarged image) of the L measurement was calculated for each month (both years combined). Although only 94 fish were examined, the data in Table 7 indicate that the first ring is formed between June and December. The value of 95 percent of scales with rings within 10-mm limits for July is probably reliable, and thus it may be assumed that winter is the season of ring formation. This means that the first yearly ring is formed when the fishes are about $1\frac{1}{2}$ years old.

Older pilchards with scales showing two or more rings were grouped together for similar analysis because it was evident that the later rings were formed in much the same season. Because

TABLE 6: Means of fish lengths and scale lengths for successive 5-mm intervals of fish length

5-mm length group	Mean body length (mm)	Mean scale length (mm)	No. of fish
30-34	34.00	0.28	1
35-39	37.00	0.46	5
40-44	42.00	0.70	8
45-49	46.54	0.85	13
50-54	52.64	1.01	11
55-59	56.65	1.12	9
60-64	62.00	1.34	10
65-69	66.80	1.46	10
70-74	72.50	1.58	6
75-79	76.40	1.76	10
80-84	81.45	2.06	11
85-89	87.00	2.29	14
90-94	91.57	2.30	7
95-99	96.87	2.55	15
100-104	101.56	2.80	9
105-109	107.18	2.86	17
110-114	112.41	2.97	29
115-119	116.91	3.09	58
120-124	121.84	3.20	61
125-129	127.13	3.32	46
130-134	131.75	3.56	51
135-139	136.49	3.72	35
140-144	142.03	3.90	29
145-149	146.79	4.08	28
150-154	152.16	4.23	31
155-159	156.87	4.45	30
160-164	161.87	4.47	23
165-169	166.18	4.72	22
170-174	171.79	4.81	19
175-179	176.50	5.11	6
180-184	182.00	5.14	7
185-189	186.80	5.46	5
190-194	192.67	5.56	3
195-199	195.00	5.94	1
200-204	204.00	6.01	1
		Total	641

TABLE 7: Number of scales with rings within 10- and 5-mm limits, for I group and II-V group pilchards

Month	1-ring scales: Total No. of scales	1-ring scales: No. of scales with ring 10 mm from margin	1-ring scales: Percent	2- to 5-ring scales: Total No. of scales	2- to 5-ring scales: No. of scales with ring 5 mm from margin	2- to 5-ring scales: Percent
Jan	13	0	0	48	11	23
Feb	1	0	0	19	3	15
Mar	4	0	0	33	5	15
Apr	6	0	0	39	3	7
May	6	1	16	18	1	5
Jun	0	0	0	18	0	0
Jul	37	35	95	19	0	0
Aug	11	8	73	24	8	33
Sep	6	4	66	31	19	61
Oct	6	4	66	68	43	63
Nov	3	1	33	24	10	41
Dec	7	6	85	104	46	44

growth is slower in older fish, the limiting value for L_2, L_3, L_4, etc., was set at 5 mm less than for L. Every effort was made to select the yearly ring rather than the condition ring (though both are apparently formed annually in mature fish), because the former was usually better defined in the apical region of the scale and more uniform in position than the latter. Nevertheless, because of the occasional absence of a yearly ring, and the difficulty in distinguishing between the two main kinds in very old fish, the wrong ring may have been selected at times. Such errors may have led to the recording of rings close to the scale margin during summer. Table 7 reveals that early spring is probably the season of ring formation in the older pilchards.

Seasonal Growth

Because scale and fish growth increments are directly proportional, an indication of seasonal growth may be obtained by comparing the marginal monthly increments (Ln to scale margin) on scales taken in consecutive months. The mean monthly growth increments have been plotted in Fig. 35 for pilchards with two and three scale rings, and show that spring and summer are the

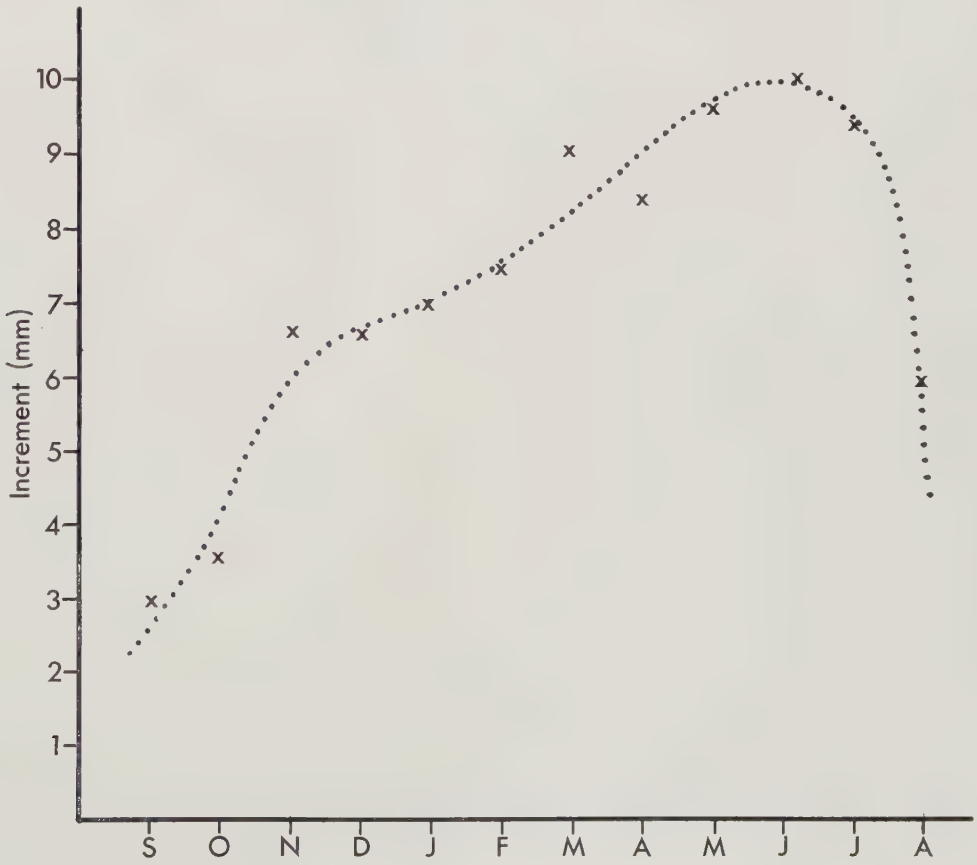


Fig. 35: Mean monthly growth increments (X) plotted for pilchards in their third and fourth years. Growth curve fitted by eye.

growing seasons. It may also be inferred from this that the yearly ring is formed toward the end of winter, near the beginning of the growing season. The condition ring, which follows closely after the yearly one, must therefore be formed later, during the season of maximum growth, which coincides with the spawning season.

Age for Size and Annual Growth

Each fish was assigned to an age group according to the number of yearly rings on its scales. Because the first ring is laid down when the fish are about $1\frac{1}{2}$ years old, and the second ring when they are $2\frac{3}{4}$ years old, etc., it follows that those with one ring (the I group) are actually in their second or even third year of life, and the II group in their third or fourth year, etc. If the yearly rings and the season of ring formation have been correctly identified, age determination can be made with greater accuracy by considering the date of capture and the amount of scale increment for each fish. For example, a pilchard caught in November with two rings and a small marginal increment is very likely to be in its third year, whereas a fish from the same catch with two rings and a large scale increment is more likely to be in its fourth year and about to form another ring.

The results of the scale readings, in terms of age for size, are summarised in Table 8. The largest pilchard with readable scales was 204 mm in body length and was probably in its ninth year; the third ring was thought to be missing, however, so that the age estimation cannot be considered completely reliable. Another fish, 195 mm long, which was caught in November, had seven yearly rings, the last of which was close to the scale margin,

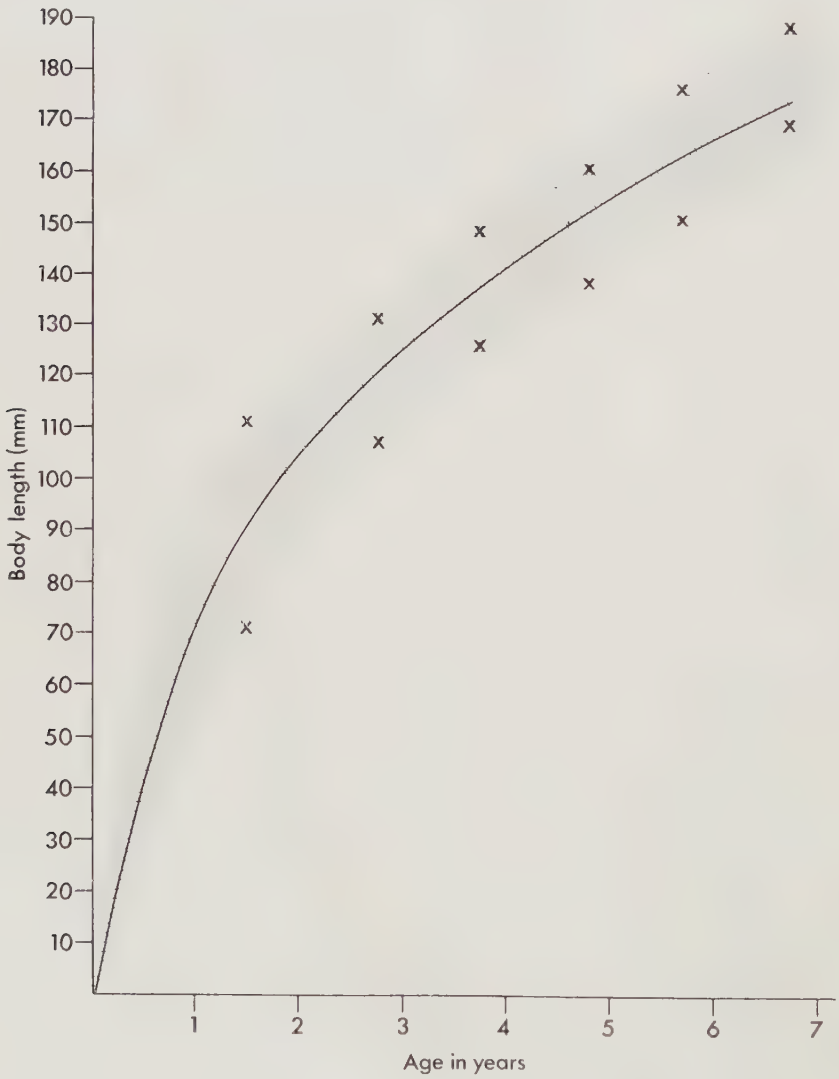


Fig. 36: Growth of the Marlborough Sounds-Tasman Bay pilchards as deduced from intermediate length data. The solid line passes through the mean intermediate lengths; the Xs show the maximum and minimum values for each yearly ring. Most pilchards probably grow at a rate which falls within the shaded area.

which indicated that the fish was about to enter its ninth year.

It can be stated then that in the Marlborough Sounds-Tasman Bay region of New Zealand *Sardinops neopilchardus* attains a maximum body length of at least 213 mm (total length 244 mm) and may attain an age of 9 years. In Australia the maximum recorded age and body length for pilchards is 6 years at 187 mm in New South Wales waters (Blackburn 1949) and 6 years at 183 mm in Victorian waters (Blackburn 1950). In a later publication (1960) that author suspected that his New South Wales determinations for large fish were too low, but still regarded his Victorian data as satisfactory.

The apparent annual growth rate of the New Zealand pilchards, as deduced from the intermediate length data, is illustrated in Fig. 36. A comparison between the growth rates of the pilchard in New South Wales, Victorian, and New Zealand waters (Fig. 37) shows that in New Zealand the

TABLE 8: Results of scale readings in terms of age for size

Length groups (mm)	Number	Age groups
45-79	83	0 group
80-84	11	0 and I groups
85-89	14	I group
90-94	7	I group
95-99	15	I group
100-104	9	I group
105-109	17	I, possibly II, group
110-114	29	I and II groups
115-119	58	I and II groups
120-124	61	I, II, and III groups
125-129	46	I, II, and III groups
130-134	51	II and III groups
135-139	35	II, III, possibly IV, groups
140-144	29	II, III, IV groups
145-149	28	III and IV groups
150-154	31	III, IV, and V groups
155-159	30	IV and V groups
160-164	23	IV, V, and VI groups
165-169	22	V and VI groups
170-174	19	V and VI groups
175-179	6	V and VI groups
180-184	7	V and VI groups
185-189	5	VI, possibly VII, group
190-194	3	VI group
195-199	1	VII or VIII group
200-204	1	VII or VIII group
Total	641	

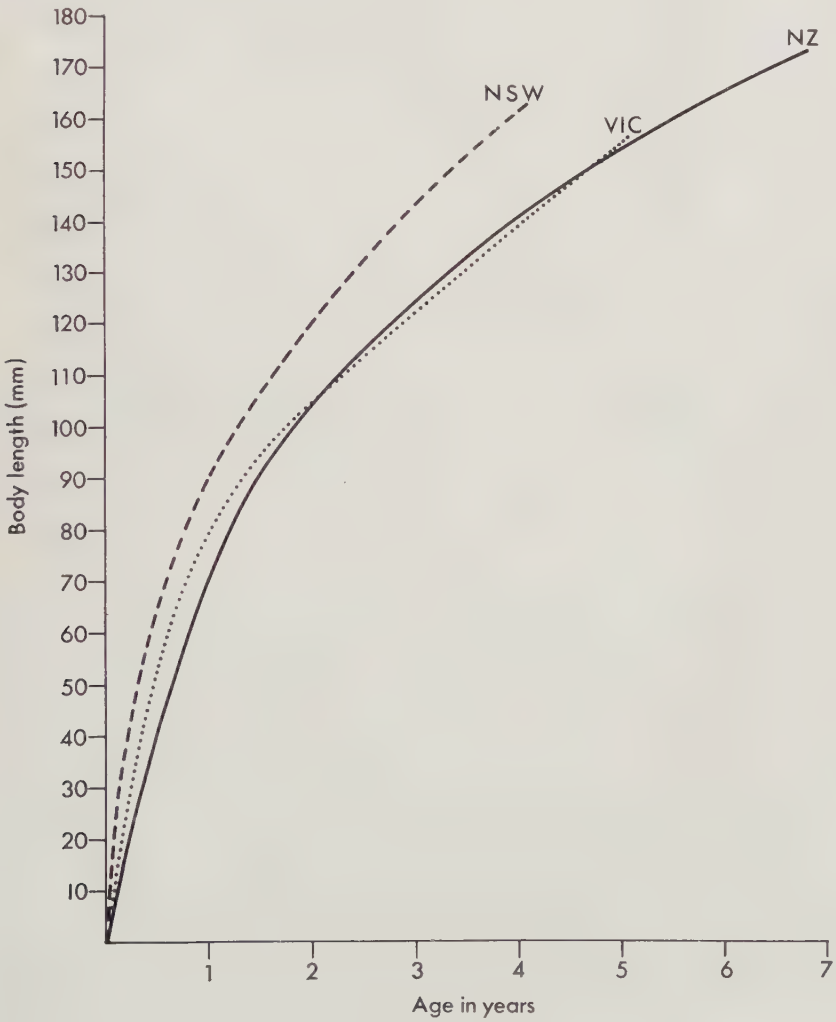


Fig. 37: Approximate growth-rate curves for pilchards from the Marlborough Sounds-Tasman Bay area of New Zealand, compared with curves for pilchards from Victoria and New South Wales, Australia. (Australian data from Blackburn 1949 and 1950.)

fish grows at about the same rate as, or slightly slower initially than, in Victoria.

The means of the calculated intermediate lengths for each $\frac{1}{2}$-cm size group of pilchards are given in Table 9. The average sizes of pilchards at the time of formation of each ring are summarised in the following series:

L_1 (age $1\frac{1}{2}$ years) = 94 mm in body length
L_2 (age $2\frac{3}{4}$ years) = 122 mm in body length
L_3 (age $3\frac{3}{4}$ years) = 138 mm in body length
L_4 (age $4\frac{3}{4}$ years) = 151 mm in body length
L_5 (age $5\frac{3}{4}$ years) = 163 mm in body length
L_6 (age $6\frac{3}{4}$ years) = 173 mm in body length
L_7 (age $7\frac{3}{4}$ years) = 188 mm in body length
L_8 (age $8\frac{3}{4}$ years) = 196 mm in body length

The mean annual growth increments (Tn), derived from the above series, show the usual teleost pattern of decrease with age:

T_1 = 94 mm in body length
T_2 = 27 mm in body length
T_3 = 16 mm in body length
T_4 = 13 mm in body length
T_5 = 12 mm in body length
T_6 = 10 mm in body length
T_7 = 14 mm in body length (3 fish)
T_8 = 8 mm in body length (1 fish)

LENGTH-WEIGHT RELATIONSHIP

The mathematical relationship between length and weight of the pilchard was determined by analysis of data from 660 fish (318 males and 342

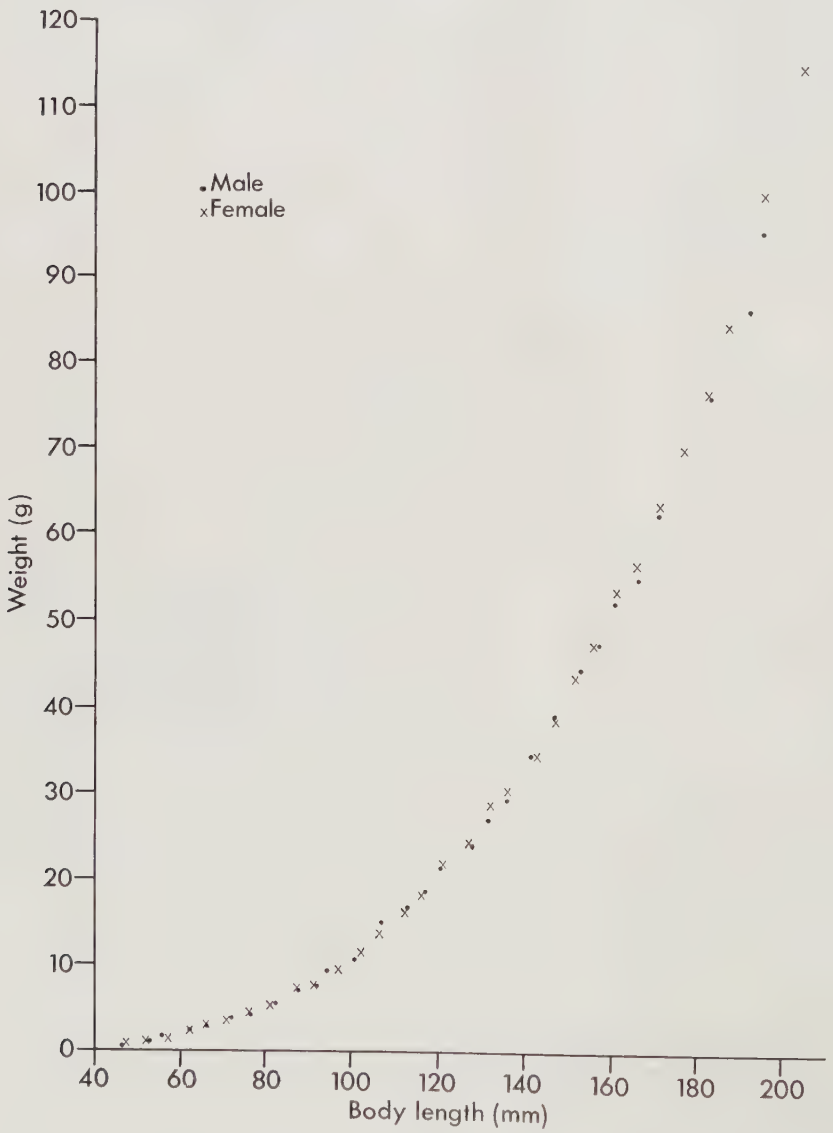


Fig. 38: Mean weights and lengths of 318 male and 342 female pilchards separately, for each $\frac{1}{2}$-cm length group.

TABLE 9: Means of calculated intermediate lengths (L_1, L_2, etc.) for successive length groups of fish (numbers of observations shown in parenthesis)

Length group (mm)	L_1	L_2	L_3	L_4	L_5	L_6	L_7	L_8
80-89	80.54 (17)							
90-94	85.82 (6)							
95-99	91.31 (15)							
100-104	92.91 (8)							
105-109	98.66 (16)							
110-114	88.33 (28)							
115-119	88.28 (50)	112.77 (23)						
120-124	93.96 (55)	118.06 (21)						
125-129	94.73 (44)	122.09 (31)						
130-134	96.33 (44)	124.02 (46)						
135-139	95.41 (27)	123.98 (28)	135.02 (5)					
140-144	96.78 (25)	123.94 (27)	136.31 (25)					
145-149	95.12 (27)	122.24 (25)	136.93 (24)	142.36 (8)				
150-154	96.45 (21)	122.28 (26)	136.61 (25)	146.79 (20)	150.20 (2)			
155-159	95.07 (28)	120.96 (25)	135.35 (25)	147.00 (26)	154.39 (7)			
160-164	94.19 (18)	120.17 (19)	136.56 (16)	150.01 (14)	156.84 (12)			
165-169	97.90 (13)	122.26 (15)	136.23 (13)	147.75 (13)	158.48 (11)	164.90 (4)		
170-174	96.50 (15)	124.41 (18)	138.02 (18)	154.24 (16)	165.92 (14)			
175-179	99.20 (6)	125.37 (6)	142.93 (6)	156.15 (6)	168.93 (3)			
180-184	98.17 (6)	124.42 (5)	142.83 (4)	157.45 (4)	169.90 (3)	178.50 (2)		
185-189	98.15 (2)	123.10 (1)	139.33 (4)	151.95 (2)	164.20 (2)	176.43 (3)	185.20 (1)	
190-194	97.25 (2)	123.83 (3)	139.03 (3)	152.53 (3)	171.00 (3)	184.43 (3)		
195-199	96.40 (1)	123.70 (1)	139.50 (1)	155.40 (1)	168.50 (1)	183.50 (1)	190.60 (1)	
200-204	96.90 (1)	126.10 (1)		155.00 (1)	167.70 (1)	178.30 (1)	188.00 (1)	196.00 (1)
Mean L_n	94.35	121.82	138.05	151.39	163.28	173.48	187.93	196.00
Total number of observations	475	351	169	108	59	14	3	1

females) which ranged in size from 47 to 204 mm and were caught over a period of 23 months. The mean weights and lengths for each $\frac{1}{2}$-cm length group are shown for males and females separately in Fig. 38.

The relationship between length and weight in fishes is usually expressed by the formula $W = aL^n$ where W = weight, L = length, and a and n are parameters characteristic of a particular population (Le Cren 1951, Pienaar and Thomson 1969). The value of n is usually between 2.5 and 4.0, which indicates an approximately cube relationship between length and weight. The best value may be obtained by a linear regression analysis in which the logarithmic form of the above formula is used:

$$\log W = \log a + n \log L.$$

The slope of the resulting regression line on a graph is represented by n and its position by log a (that is, $y = a + nx$, where y and x are points on the ordinate and abscissa respectively).

A logarithmic plot of the observed means is shown in Fig. 39; the line has been fitted by the formula $y = a + nx$ with combined male and

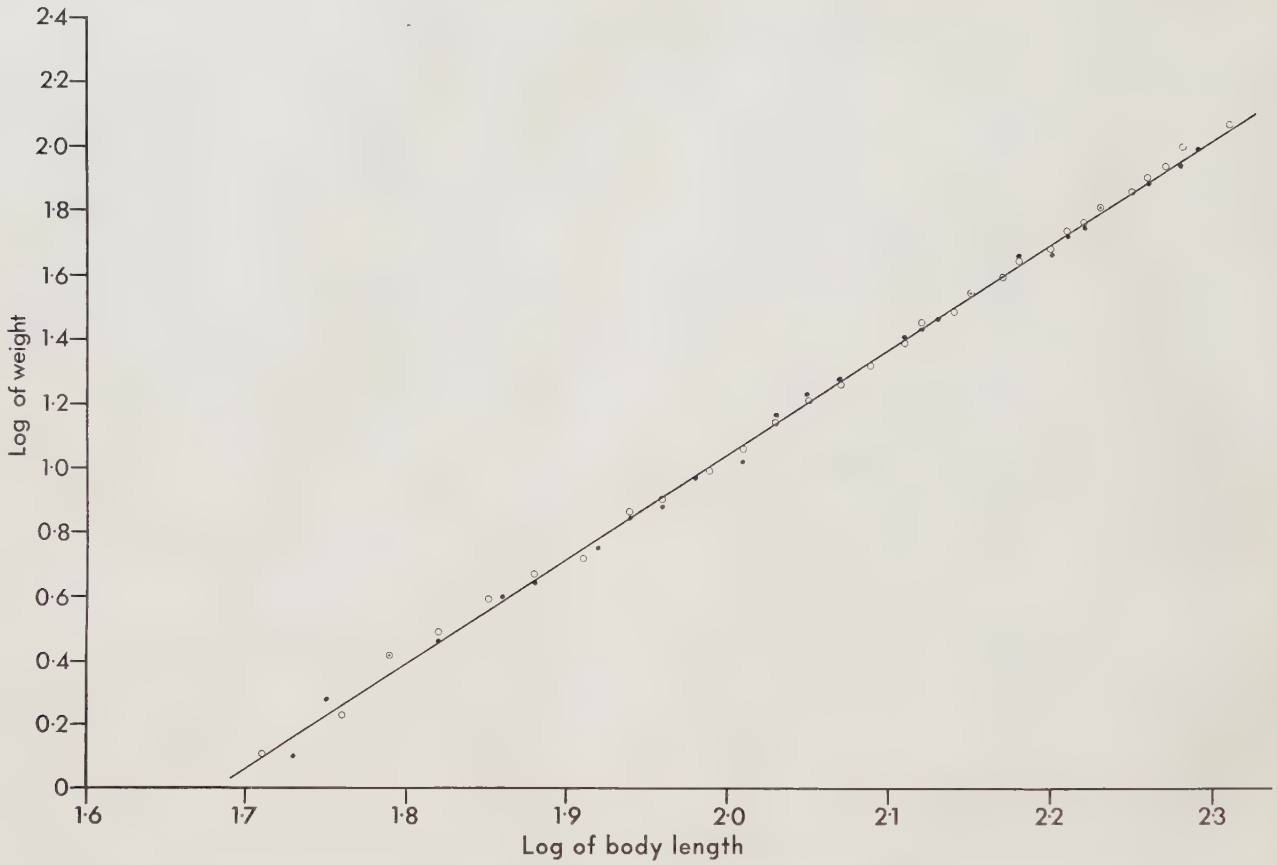


Fig. 39: Logarithms of the mean weights and lengths for each $\frac{1}{2}$-cm length group of 318 male (closed circles) and 342 female (open circles) pilchards. Regression line fitted by the combined male and female equation: $y = \bar{5}.4355 + 3.2399x$.

female values of a and n. The equation for the combined data is $y = \bar{5}.4355 + 3.2399x$, and may be expressed by the original formula $W = aL^n$ as $W = .000003668\ L^{3.2399}$. Thus, the weight of the pilchard increases at a rate slightly greater than the cube of its length.

SUMMARY

The pilchard *Sardinops neopilchardus* appears to be widespread in New Zealand coastal waters; it is present in the Marlborough Sounds-Tasman Bay area throughout the year, but is commonest between October and April, when it forms surface shoals. The New Zealand population of this species is distinct from Australian populations; it has larger eggs, grows larger and older, and has a higher mean vertebral number.

The study of seasonal gonad activity, changes in maturity coefficient, and the occurrence of eggs and larvae in the plankton showed that pilchards spawn between November and February in the Marlborough Sounds-Tasman Bay area. Pilchards probably spawn throughout the year in northern New Zealand. Few pilchards mature at a body length less than 120 mm, about half mature at lengths between 120 and 124 mm, and practically all are mature at 135 to 139 mm. Most fish do not begin spawning until their third or fourth year. Large mature females contain up to 110,400 eggs.

Spawning takes place throughout most of the Marlborough Sounds-Tasman Bay area, but is more concentrated in Tasman Bay. Eggs were recorded between temperatures of 14.7° and 20.9°C and at depths between 0 and 30 m. These temperatures are likely to be near to the minimum and maximum values at which spawning can take place. The pilchard egg is very characteristic: it has a single small oil globule and a large perivitelline space and it ranges between 1.32 and 1.70 mm in diameter. The duration of development to hatching was 45 to 49 hours at a mean temperature of 19.6°C and 56 to 58 hours at 16.5°C.

Pilchard larvae are between 2.2 and 2.6 mm long at hatching and float near the surface with the attached yolk sac uppermost. The yolk is absorbed when the larvae are from 5.0 to 5.5 mm long. Metamorphosis from post-larva to juvenile takes place at lengths between 35 and 40 mm and involves changes in body form and pigmentation.

Pilchards grow rapidly in their first year and attain a mean body length of from 55 to 60 mm. In their second winter of life, at $1\frac{1}{2}$ years of age, a ring is laid down on the scales; this probably coincides with the slowing down or almost complete cessation of growth during winter. In subsequent years growth takes place during spring and summer and slackens off again during winter, and a scale ring is formed each year near the end of winter or in early spring. In mature fish a condition ring is formed on the scales soon after each yearly one.

The growth increments of scale and fish are directly proportional in the pilchard, and the growth of adult fish can be estimated from scales by back calculating fish lengths at the time of ring formation. The mean body length of fish at ring formation is about 94, 122, 138, 151, 163, and 173 mm for rings 1 to 6 respectively. The ages of fish at these lengths would be about $1\frac{1}{2}$, $2\frac{3}{4}$, $3\frac{3}{4}$, $4\frac{3}{4}$, $5\frac{3}{4}$, and $6\frac{3}{4}$ years respectively. In the Marlborough Sounds-Tasman Bay area pilchards attain a body length of at least 213 mm (total length 244 mm) and a probable maximum age of 9 years.

The length-weight relationship of the pilchard may be expressed by the equation

$$W = .000003668\ L^{3\cdot2399},$$

which represents combined male and female data. Differences between the sexes were slight.

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